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MONTHLY WEATHER REVIEW, June, 1928, page 241:

The crest stage at Carthage, Tenn., published as "54.2" should be "45.2".

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THE 28-MONTH PERIOD IN SOLAR ACTIVITY AND CORRESPONDING PERIODS IN MAGNETIC AND METEOROLOGICAL DATA

By HOMER W. CLOUGH

[Weather Bureau, Washington, July, 1928]

SYNOPSIS

Periods in the strict sense of the term have not been discovered either in solar or meteorological data. However, the variation in spottedness of the sun over an irregular period of roughly 11 years represents a type of period which may vary in length systematically, and such periods are found in both classes of data.

The periodogram analysis has given very uncertain indications of the existence of periods of constant length, and it is pointed out that the results of such methods of analysis are entirely consistent with the hypothesis of variability in periods and can be properly interpreted only by the aid of other methods of analysis.

By means of statistical methods results are obtained which, interpreted by certain criteria, indicate the existence and probable length of a more or less regular recurrence. The period is isolated either by employing suitable smoothing formulae or by a free-hand smoothing of graphs or a combination of both methods. Epochs of maxima and minima are then selected from the graphs and their reality determined by non-mathematical criteria which are peculiar to the methods employed.

A summary is given of the various kinds of solar data made use of, and it is pointed out that since only one-half of the solar surface is visible at any time there must necessarily result more or less irregularity in the variations of periods, especially the shorter ones.

The mean heliographic latitude of the entire spotted area has a well-marked 11-year variation in which there is a maximum excess of spots in the northern hemisphere three to four years before the epoch of sunspot maximum and a maximum excess in the southern hemisphere about a year before the sunspot minimum. When the average latitude of spots is high, there is an excess of spots in the northern hemisphere; when low, there is an excess of spots in the southern hemisphere.

When the 11-year variation is eliminated from the latitude data in half-yearly means, there are disclosed short period variations of irregular length, the mode or most frequent length being about 2.4 years. If these variations were of a purely accidental nature, the most frequent length would average about 1.6 years. Self-correlation of the data likewise indicates a well-marked recurrent feature of about 2¼ years in length. These two results should be regarded, in view of the strictly impersonal character of the results and the wide divergence from random data, as adequate evidence for the existence of a periodicity in the latitude data. Definitive epochs of maxima and minima from 1855 to 1925 are given and the average length of the period is found to be 2.55 years with the most frequent interval 2.50 years.

After the 11-year variation is eliminated, this short period appears in the relative numbers as well as in their scatter, as measured by the interdiurnal variability. It is less regularly shown, however, than in the latitude data.

The epochs of maxima and minima derived from the relative numbers indicate that the length of the period is around two years at sunspot maxima and three years at sunspot minima. This result is consistent with the fact that a relatively short interval occurs between a minimum and a maximum phase when the latter is exceptionally intense.

There are given new determinations of the epochs of maxima and minima of the elemental 11-year variation in the relative numbers.

New determinations of the 11-year epochs of maximum and minimum magnetic declination range are given and there are derived epochs of the 28-month variation in the range. These epochs average about .07 year later than the corresponding epochs for the relative numbers.

An 11-year variation occurs in the length of the 28-month period in terrestrial temperatures with long and short intervals about four years after the Wolfer epochs of minima and maxima respectively.

The short period variations in temperature have a closer causal relation to the solar latitude than to the relative number variations. It is found from data extending over a period of 75 years that the epochs of maximum and minimum temperature occur about one year later than the epochs of maximum southern and northern heliographic latitude respectively, and about four months before the epochs of minimum and maximum spottedness.

A discussion of the significance and evidential value of the results of the investigation follows and certain criticisms are answered.

INTRODUCTION

The dependence of the meteorological phenomena of the earth upon the variations of solar activity has been affirmed by many investigators. Two important relations seem to be well established, viz, the inverse relation between both the temperature and the pressure in the equatorial regions and the solar spottedness. The relation between temperature and spottedness holds also for the entire globe but the amplitude of the variation decreases with increasing distance from the tropics. Employing yearly means of the meteorological elements and of the sunspot relative numbers, an 11-year variation in temperature is found with phases in opposition to those of the solar cycle.

A variation in the number of prominences at intervals averaging three to four years has been compared with meteorological elements with some success by Lockyer and Bigelow, but the results have been rather more suggestive than conclusive. A three-year variation in temperature and pressure in the equatorial regions, particularly in the Indian Ocean area, has been studied by numerous investigators. The correlation of monthly values of meteorological elements and the sunspot numbers has not led to any decisive results.

Practically all investigators of solar and meteorological variations have assumed that periods should be of uniform length and accordingly have employed the periodogram analysis, but the results have not favored the hypothesis of the existence of such periods, and the reasonable inference is that they do not exist in meteorological data, since they have not been found in solar data. However, it must not be lost sight of that the results of such a periodogram analysis are not inconsistent with the possibility of the existence of periods variable within reasonable limits and rightly interpreted can not conflict with the findings by other methods.

On the other hand, all available evidence, properly interpreted, points to the existence of periods with a certain average length but variable within limits such that the longest period may be twice the shortest. The so-called 11-year period of solar spots is, it is well known, not of uniform length. The best value of the period as determined by Newcomb employing least square methods is 11.13 years. During the last 300 years the 56 intervals,

maximum to maximum and minimum to minimum, have ranged between 7.3 and 17.1 years, half of them being less than 10 or greater than 12 years. The writer has shown elsewhere (*1*) that this variation, instead of being accidental, is in reality highly systematic, being controlled by a 36-year period, so that it is possible to predict the next epoch of maximum or minimum with a higher degree of accuracy, in the long run, than if merely the normal interval of 11.13 years had been employed. As to the short meteorological period of about three years, referred to above, the writer in a recent paper (2) showed that it is clearly apparent in high latitudes of the Northern Hemisphere as well as in the Tropics. Its length averages 28 months but varies systematically under control of the solar 11-year and 36-year periods. He further showed that this period exists in solar phenomena.

The propriety of designating by the term "period" a sequence which varies systematically is questioned by some meteorologists. However, astronomers have long been accustomed to designate as periods such irregular recurrences as that of maximum solar spottedness and the maximum brilliancy of variable stars. We may, therefore, regard this practice as an instance of a meaning inconsistent with the primary significance of a word but sanctioned by usage.

The present investigation has for its object the determination of definitive epochs of maxima and minima for the 11-year and 28-month periods in various solar and magnetic phenomena. From these epochs we derive the average length of the periods as well as the systematic variations in their lengths. The amplitude of the periods is of equal importance but for various reasons can be less satisfactorily determined. Necessarily the amplitude of period shorter than the 11-year period, derived from the relative numbers, must vary with the position in the 11-year cycle, since the scatter of the relative numbers as measured by the month-to-month variations is least at minima and greatest at maxima. Other solar data, however, have short period fluctuations with amplitudes equal to that of the 11-year variation in the data.

The writer's earlier paper (2) referred only briefly to the 28-month *solar* periodicities, and the present paper is intended to present additional evidence regarding the 11-year and 28-month variations in the mean heliographic latitude of the spotted area and other features of solar activity.

MATERIAL AVAILABLE FOR ANALYSIS

Solar data.—The solar data available for analysis are mainly the Wolfer series of epochs of maxima and minima beginning with 1610, and the relative numbers which comprise approximate yearly values from 1700 to 1749 and monthly values from 1749.

The Wolfer relative number is derived by the formula, $r=k(10g+f)$, in which g is the number of groups and isolated spots observed and f the total number of spots which can be counted in these groups and singly, while k is a coefficient depending upon the observer and his telescope. The relative number is, therefore, an index of the relative frequency of spots and groups.

Other solar data includes measurements of areas and positions of sun-spot groups from a projected image or a photograph. The Carrington and Spoerer series of solar observations give areas and positions of spot groups from 1854 to 1890. The Greenwich measurements of daily photographs from 1874 give the heliographic latitude and longitude of each group of spots with its area in millionths of the sun's visible hemisphere. These daily measures are combined into means for each rotation period and for the calendar year.

The Lyons Observatory, beginning with 1889, using a projected image of the sun, has published measurements of areas and positions of sun-spot groups, with means by calendar months. These data agree satisfactorily with the Greenwich data.

Other observatories such as Rome, Catania, and Kodaikanal have published various solar data including the mean daily number of groups, separate spots and pores while the Observatory of the Ebro has since 1910 daily measured the areas of the calcium flocculi.

Statistics of faculæ and prominences are other solar data available but since these two features are confined to a small area at or near the solar limb, their occurrence necessarily gives only incomplete information regarding the solar activity.

It is to be borne in mind that only one-half of the sun's surface is visible at any one time. Since the spots are practically the only available indication of solar activity, the daily measurements furnish only one-half of the total external evidence of activity. As a result there should be expected more or less irregularity in the various solar periodicities, since one-half the data is lacking. This irregularity will be especially noticeable when spots are few, and it is evident that the shorter the period the less regular the variation is likely to be.

The 11-year period is probably not affected greatly by this deficiency in the data as far as the total spottedness is concerned. The areas by hemispheres are likely to show considerable irregularity. The 28-month period is much more difficult to trace in the relative numbers and the still shorter periods are even more obscure. Fortunately the ratios of the spottedness of the two hemispheres seem to show the periods with greater regularity than do the total areas or the relative numbers, at least for the shorter periods.

The hypothesis of the continuity of solar periodicities is the one which seems to fit the facts most satisfactorily. Although they are difficult to trace at times owing to the unavoidable lack of complete data, their continuity and the strongly systematic character of their variations enable one to determine satisfactorily epochs even where the evidence is uncertain. In such cases it must be considered that if complete data were available the uncertainty would disappear.

Magnetic data.—Still another index of solar variability is the magnetic activity of the earth which synchronizes closely with solar activity. The 11-year variation in sun-spot numbers is strikingly reproduced in certain magnetic data, particularly the solar diurnal range of declination, and the shorter variations in these phenomena are also more or less highly correlated.

These various kinds of solar and magnetic data are strictly independent of each other and disclose widely different aspects of the sun's activity. They are of varying degrees of accuracy, depending largely upon the judgment of the observer and the local conditions of seeing and equipment. Only the Greenwich solar measures and certain magnetic data can be said to be independent of human judgment. Even magnetic data have a terrestrial element which renders it difficult to identify common features in them which may be correlated with solar variations.

Data analyzed by graphical methods.—The method of analyzing data employed by me is largely an empirical one. The probable existence of a periodicity is shown by a preliminary examination of smoothed graphs and a tabulation of the frequencies of the intervals between

the more pronounced crests and hollows. Tentative epochs of maxima and minima are then selected directly from the graphs and their reality confirmed by the aid of various criteria which are distinctive of the methods employed.

A principle which has been adopted as a working hypothesis in the selection of epochs is that the intervals between adjacent epochs should be as uniform as possible and that variations in the successive intervals should be in accord with the principle of continuity. There should be no abrupt change from very short to very long intervals. This is a reasonable working hypothesis, and it was found in the course of the investigation that this hypothesis comes closer to fitting the facts than any other. Of course, it must be realized that individual intervals are subject to rather large errors of estimation due to the rough method of selection and the effect of other periods, but a smoothing of successive intervals by moving averages of three terms will show that the changes occur gradually.

This is equally true of physical variations which are *not* periodic.

In endeavoring to determine by graphical methods any periodicities which may exist in a body of data, as for example the Wolfer relative numbers, it is highly advantageous to prepare graphs not only of the original data but also of various combinations of the data that may be derived by simple arithmetical methods. By a judicious treatment of the data it may be possible to discover relations that are only obscurely apparent in the original data. Perhaps the simplest illustration of treatment of data herein recommended in order to disclose more clearly periodic phenomena is Wolfer's method of adjusting monthly values of the relative numbers by a simple smoothing formula in order to eliminate irregular variations of shorter duration than a year, thereby facilitating the determination of the date of an epoch to the tenth of a year. Further illustrations of such treatment of data will be given below.

Again we may obtain from a single series of data two or more quasi-independent curves showing similar systematic variations with corresponding maxima and minima, which, however, may be unequally developed and even nonsynchronizing as to phase. If there is an underlying periodicity, it should be apparent in each of the curves, although not necessarily in equal distinctness.

THE 11-YEAR PERIOD IN SOLAR PHENOMENA

The various solar phenomena more or less directly associated with the sun spots, as the faculæ, flocculi, and prominences, have 11-year maxima and minima closely synchronizing with like phases of the spots.

A dominant feature of solar activity apart from the variations in the area and the frequency of spots is the 11-year variation in their latitude, manifest in the shift from high to low latitude and from one hemisphere to the other.

The mean latitude of spots has an 11-year period of variation. According to Spoerer's law the mean yearly values of the latitude are highest, around 20° to 25°, about a year after the epoch of minimum spottedness and lowest, around 6° to 8°, about a year before the following epoch of minimum spottedness.

Relation between the two solar hemispheres.—When we consider the two hemispheres separately we find that while they show roughly the 11-year period in their spottedness their epochs of maxima and minima are not coincident but differ at times a year or more. I have derived these epochs from the Carrington and Greenwich series of yearly values of frequency and spotted areas for each hemisphere. Minor irregularities were eliminated by consecutive 3-year smoothing which made it possible to determine the epochs to one or two tenths of a year by simple inspection of the smoothed values. From 1854 to 1870 the epochs for the southern hemisphere preceded those for the northern, the maximum difference being 0.5 year. At the maximum of 1870 the two epochs coincided. Since 1870 the northern epochs have preceded the southern epochs with a maximum difference of 1.2 years and an average difference of 0.5 year. For the whole series, 1854–1923, the average lag of the southern hemisphere has been 0.3 year.

The extent to which the two hemispheres vary together is indicated very clearly by correlating their mean variations for time units varying from one month to three years. The following coefficients have been computed by the method based on variate differences which has been explained in my former papers. Three-year means, 1874–1924, +0.91. Yearly means 1874–1924, +0.65. Five-rotation means, or 136 days, +0.37. 27-day means, 1874–1889, ±0.00. Monthly means, 1908–1924 (Lyons Obsy.) −0.10.

Evidently for short periods, as a month, the correlation is around zero. As increasingly longer units of time are employed, the positive correlation increases until, with minor year-to-year irregulatities eliminated, the 11-year variation common to each hemisphere yields a correlation above +0.90. It is clear therefore that the spotted areas of the two hemispheres vary in absolute independence of each other during short periods of time. Obviously, the investigation of total spottedness for evidence of short periodicities is likely to be disappointing.

The mean heliographic latitude.—There is, however, a method of combining the data from the two hemispheres which I have found to yield very definite results. The Greenwich reductions give for each day the latitude and area of each group of spots. The group latitudes are given weights proportional to their areas and thus there is derived a weighted mean latitude for each day which is designated as the mean heliographic latitude of the entire spotted area. These daily values are combined into means for each rotation period and for the calendar year, and have been used in what follows. The calendar year means are given in Table 1, column 4. For convenience these mean values will hereafter be designated as H. L. values. North H. L. is regarded as plus and south H. L. as minus.

Around epochs of minima there are frequently months with a total absence of spots. Obviously the H. L. has no value in those months and they are disregarded in combining monthly values into half-yearly or yearly means. This gives rise to considerable irregularity in periodicities of three years and under, at spot minima. Flocculi are observed continuously even when spots are absent and very satisfactorily supplement the spot data at such times.

The calendar year means of the H. L. are shown in Figure 1, curve 1, and the values, smoothed by the formula $(a+2b+3c+2d+e)\div 9'$, are shown as a dotted line. This curve shows a well-defined 11-year period in which the H. L. is farthest north three to four years before the maximum of spots and farthest south about a year or two before the minimum. The mean range of this 11-year variation in the mean H. L. is about 6°.

Ratio of northern to total spotted area.—Another method of showing this period is by computing yearly values of the percentage of spots in the northern hemisphere rela-

tive to the spottedness of the entire area. These percentages are given in Table 1, column 3. Curve 2 in Figure 1 shows the actual values and smoothed values are shown by the dotted line.

It is evident from the similarity between curves 1 and 2 that the percentage of spotted area in the northern hemisphere, derived by a simple operation, yields results similar to those disclosed by the mean heliographic latitude which is obtained only by a laborious computation.

Results of Carrington's and Spoerer's observations.—The observations by Carrington and Spoerer of the number and mean latitude of spot groups form a continuous series from 1854 to 1894, and enable us to trace back this variation in the H. L. 20 years before the beginning of the Greenwich record. The overlapping period of 20 years, common to the two series, serves to confirm, at least for the shorter variations, the general accuracy of the Spoerer record, which of course is not complete owing to lapses due to cloudiness, and is not strictly homogeneous with the Greenwich record, being a record of frequency, while that of Greenwich refers to the spotted area.

Beginning with 1854 there are available mean frequencies and latitudes of groups for each hemisphere with the mean H. L. The yearly values of the mean H. L. and the percentages of spot frequency in the northern hemisphere are given in Table 1, columns 1 and 2, and shown as curves 1 and 2 in Figure 2.

The 11-year variation shown by the smooth curve is clearly evident, the mean H. L. being farthest south at or shortly before a minimum of spotted area. The epochs of extreme southern displacement are 1857.5, 1868.0, 1877.0, 1889.0, 1899.5, 1911.5, 1920.5. It is noteworthy that the two belts of spots in the two hemispheres are nearest the equator when the southern hemisphere is relatively more spotted than the northern hemisphere, at or near the above epochs of extreme southern H. L.

THE 28-MONTH PERIOD IN SOLAR PHENOMENA

The 28-month period in the H. L.—It is evident from curves 1 and 2, Figures 1 and 2, that a short fluctuation of considerable amplitude is superposed upon the 11-year variation. That it is not a purely fortuitous fluctuation is seen from an analysis of the frequencies of the intervals between successive crests and hollows of curve 1, employing the annual means from 1874 to 1925. The frequencies, in percentages, of the 2-year, 3-year, etc., intervals are given below, with the probable frequencies for random data (3). The total number of variates is 31.

Interval in years	2	3	4	5	6
H. L. data, per cent	20	47	23	7	3
Random data, per cent	40	33	17	7	2

In purely random data the two-year interval is the most frequent, while in the H. L. data the three-year interval is the most frequent, indicating markedly systematic characteristics and consequently the existence of a tendency to recurrence. The length of this short variation ranges between two and four years.

In order to determine more precisely the main features of this short variation the mean H. L. was computed for each half year from the Greenwich mean values by solar rotation periods. The approximate mean values for the months January to June, inclusive, and July to December, inclusive, were thereby determined. These means were given in my paper (2) on the 28-month period, page 436, previously referred to, and are reproduced in Table I, columns 5, 6, and shown as curve 3 in Figure 1 with a free hand curve drawn to indicate the general trend of the short 28-month fluctuation.

A similar curve 4 can be derived from the values of the areas in the northern hemisphere, expressed as a percentage of the entire spotted area. Curves 5 and 6 show the Greenwich data as a frequency exhibit with the number of months in each half-yearly period having a north H. L., or an excess of spots in the northern hemisphere, expressed as a percentage of the total number of rotation periods, six or seven, which were combined into the half-yearly means. These two curves resemble each other rather closely, as should be expected, and are also highly correlated with curves 3 and 4.

The short fluctuation is shown to better advantage on eliminating periods of longer duration, as the 11-year variation. This is accomplished by taking residuals from the H. L. data smoothed by the formula $(a+2b+2c+2d+2e+2f+g)\div 12$. These residuals, 96 in number, further smoothed by the formula $(a+2b+c)\div 4$, are given in Table, 1 columns 7, 8, and shown graphically as curve 7, Figure 1.

The markedly systematic character of this curve is evident from the following tabular presentation of a comparison of the relative frequencies of the intervals between consecutive maxima or minima with those of random numbers (3) smoothed by the formula $(a+2b+c)\div 4$. The total number of variates is 40. The unit data are half-yearly means.

Interval	2	3	4	5	6	7	8
H. L. data, per cent	0	11	31	34	11	8	3
Random data, per cent	3	30	24	18	13	8	4

The most frequent interval for random numbers is the 3 interval, while for the solar data it is about 4.75 or 2.38 years since the unit data are half-yearly means. This frequency tabulation furnishes a better value of the probable length of the sequence than the previous tabulation which was based on annual means.

Correlating these H. L. residuals, both smoothed and unsmoothed and the same data with successive half-yearly shifts, there are obtained the following coefficients. The number of variates is 100.

Lag in years	0.0	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0
Smoothed r	+1.00	+0.36	−0.76	−0.52	+0.46	+0.48	−0.18	−0.14	−0.11	+0.49	+0.19
Unsmoothed r	+1.00	−0.50	−0.34	−0.20	+0.23	+0.37	−0.31	−0.39	+0.18	+0.42	−0.19

The maximum positive coefficients are at about 2.25 and 4.5, indicating a length of period of about 2.25 years. The coefficients from the unsmoothed data are less regular than from the smoothed data and the maximum at 2.5 is smaller but the phases of the two sequences are substantially coincident. Obviously the value for the recurrent feature, 2.25 years, is not due to the smoothing process.

In order that the reader may realize that the maximum positive coefficients, around +0.48, for the first and second recurrences at 2.25 and 4.5 years are really relatively large and undoubtedly indicate the existence of a recurrent feature in the data, a comparison with a similar self-correlation of the yearly relative numbers from 1750 to 1925 is given. For this period of time, 175 years or about 16 recurrences of the 11-year period,

the series of coefficients for varying lags up to 25 years shows the first maximum positive value +0.59 at 11 years and the second +0.48 at 23 years. Thus for the 11-year period whose existence is well established, we have a coefficient for the first recurrence not much greater than that for the short period. Dividing the sunspot data into two parts and correlating each part separately we find for the first half, 1750–1829, +0.48 as the maximum coefficient at 10 years, and +0.70 as the maximum coefficient at 11 years from 1830 to 1925. The large variability in the length of the period in the first half of the series accounts for the low coefficient.

These values of the probable length of the period obtained by the method of self-correlation and the frequency tabulation of the intervals between crests and hollows are, of course, only rough approximations. The average length, like that of the 11-year period, is derived from the epochs of maxima and minima, selected after a careful study of curves 3–7, Figure 1. This selection of the epochs is facilitated to a certain extent by a knowledge of the approximate value of the period length

The Carrington and Spoerer series of observations from 1854 to 1894 are also combined in periods of five solar rotations, making about 2.5 values per year. These observations comprise the number of groups and their mean latitude for each hemisphere. I have derived the mean H. L. for each of these periods by computing for each hemisphere the product of the number of groups and the mean latitude. The difference between the two products divided by the total number of groups gives the H. L. These H. L. values, smoothed by the formula $(a+b)\div 2$, are shown as curve 3, Figure 2, with a free-hand curve drawn to indicate the trend of the 28-month variation. The 20-year overlap in the two series shows substantial agreement between records based on frequencies and on areas.

The definitive epochs of maxima and minima derived from the H. L. curves are given in Table 2, columns 1, 2.

The following table shows the frequencies of the H. L. intervals between maxima and minima, Table 2, column 3, expressed in percentages of the total number of variates, 53. There are given for comparison a frequency tabulation of the Wolfer 11-year intervals, in percentages of the total number, 55.

H. L. 28-month intervals		Wolfer 11-year intervals	
Years	%	Years	%
1.50	2	7.4	2
1.75	4	8.3	9
2.00	15	9.2	9
2.25	15	10.1	18
2.50	30	11.0	24
2.75	9	11.9	15
3.00	11	12.8	7
3.25	2	13.7	11
3.50	8	14.6	4
3.75	4	15.5	0
		16.4	0
		17.3	2

It is clear that there is little difference in the two series as far as variability in the intervals is concerned. The Wolfer intervals range between 7.3 and 17.1 years, the most frequent interval being 11 with 24 per cent. The H. L. intervals range between 1.50 and 3.75 years, the most frequent interval being 2.50 with 30 per cent. The five intervals, 2 to 3, comprise 80 per cent of the whole number. The average interval is 2.56 years. The distribution, like that of the Wolfer intervals is unsymmetrical with a positive skewness, the mode being less than the mean. The mean deviation of the intervals from 2.5 years is ±0.38 year.

The 28-month period in the relative numbers.—The 28-month period, while clearly evident in the H. L. data, is discernible in the relative numbers only after the 11-year period has been eliminated. The simplest way to effect this elimination is to compute from the monthly numbers half-yearly means ending June 30 and December 31 for each year, and combine these into running means of five. Each of these latter means comprises therefore a period of 30 months, or about the length of the short period. Residuals of this smoothed series from the original data give the short period freed from the 11-year variation, or any other long-period variation. These residuals are given in columns 9, 10, Table 1.

When this is done, there appear secondary spot maxima and minima one to two years after the epochs of maximum north and south H. L., respectively. These spots of maxima and minima are given in Table 2, columns 5, 6. This lag is analogous to that of three to four years in the case of the 11-year variation. The lag, therefore, varies directly with the length of the period. Curve 8, Figure 1 is a graph of the residuals of the relative numbers.

For convenience the Wolfer relative numbers will be hereafter designated as S. S.

The S. S. curves, even after the elimination of the long period variations, do not show the 28-month period as regularly as do the H. L. curves. At times the maximum or minimum of spots corresponding to an H. L. epoch is not well defined. Since, as stated above, the correlation between the spotted areas of the two hemispheres is around zero, it follows that the correlation between the ratio of their spottedness, or the H. L., and the total spottedness must be relatively low. The general tendency, however, is toward a positive correlation, allowing for a lag in the S. S. data, varying with the length of the period.

The 28-month period in the interdiurnal variability of the relative numbers.—Another series of solar data is the interdiurnal variability of the Wolfer sunspot numbers or the mean variability of the daily relative numbers. The writer has computed monthly and half-yearly means of this element since 1873. This measure of the scatter of these numbers is a quasi independent series of data, coequal in importance with the monthly numbers themselves. When the 11-year variation is eliminated from these values by the same method employed for the relative numbers, there are obtained residuals which show a correlation of +0.81 with the S. S. residuals. These residuals are in columns 11, 12, Table 1, and are graphically shown as curve 9, Figure 1. The curve shows the 28-month variation even better than does the curve of S. S. residuals. The phases of the two curves are nearly synchronous, there being a lag of about 1½ months, on the average, in the phases of the S. S. curve. Correlating the S. S. residuals with the variability residuals six months earlier, coincident with, and six months later, there are obtained coefficients, −0.10+0.81, and −0.45, respectively, which conform the existence of the small lag in the S. S. residuals.

The 11-year variation in the length of the period.—A well-defined systematic variation in the length of the 28-month period is clearly evident from an analysis of the H. L. and the S. S. epochs in Table 2. The columns following the epochs give the intervals between consecutive maxima or minima and in columns 4 and 8 are given the intervals smoothed by the formula $(a+b+c)\div 3$. These smoothed intervals are shown in Figure 3, curves

1 and 2, plotted opposite the dates midway between the epochs of maxima and minima. The 11-year variation is evident in these series of intervals but is more regular in the curve derived from the relative numbers. Table 3 gives the 11-year epochs of maximum and minimum length of the period, from which it appears that there is a persistent opposition of phase between the two curves, maxima and minima, of the H. L. curve corresponding to minima and maxima, respectively, of the S. S. curve.

The epochs of long and short 28-month intervals, derived from the relative numbers, occur near the Wolfer epochs of sunspot minima and maxima, respectively, and precede them with an average interval of 0.6 year. In other words, near epochs of sun-spot maxima the solar activity increases and one result of this increased activity is a decrease in the length of the short period of 28 months. An analogous relation is seen in the relatively short interval between a very intense 11-year maximum phase and the preceding minimum.

The 36-year variation.—There is also evident from a careful study of the graph (Fig. 3, curve 1) a 36-year variation in the length of the short period, long intervals occurring about 1860 and 1893, and short intervals about 1875 and 1912.

The lag in the epochs of spottedness.—It was shown above that the mean H. L. is farthest north 3 to 4 years before the Wolfer epochs of maximum spottedness. A similar lag in spottedness is evident in the 28-month variation. Table 2, columns 13, 14, gives the lag or the interval from the epochs of H. L. to those of S. S. The average lag from 1855 to 1925 is 1.35 years. However there are marked systematic variations in the lag, an 11-year variation being very evident. These lags smoothed by taking means of three are shown as curve 3, Figure 3, from which are derived the 11-year epochs which are given in Table 3. These epochs of long and short lags average about 2 years after the Wolfer epochs of minima and maxima, respectively. The 36-year variation is also evident, with maxima around 1857 and 1890 and minima around 1874 and 1905.

Continuity and independence of the 28-month period.—A careful examination of curves 8 and 9, Figure 1, should convince one of the unbroken continuity of this secondary variation of solar activity. Freed from the 11-year variation, the epochs furthermore show no relation whatever to the Wolfer epochs. The two periods are incommensurable with and independent of each other.

This is further evident on referring to the graph of actual and smoothed relative numbers in the MONTHLY WEATHER REVIEW, April, 1902. At certain 11-year maxima, as 1770, 1803, 1830, 1870, 1883, there are two short-period crests about two years apart with not greatly differing ordinates; likewise at certain 11-year minima, as 1755, 1798, 1823, 1877, 1888, 1912, there are two nearly equal scondary minima, about two years apart, separated by a secondary maximum.

A new determination of the 11-year epochs of maxima and minima.—It is clear from this graph that these secondary fluctuations have a considerable amplitude around sunspot maxima and that by employing a smoothing formula of only 12 terms, as Wolfer did, the 11-year maximum epoch of spottedness is made to coincide frequently with a secondary maximum of spottedness. The logical inference is that the short period must be properly eliminated in order to obtain the most probable date of the 11-year epochs. Wolfer's epochs were read off from a composite curve and do not truly represent epochs of the elemental 11-year variation.

In order to eliminate this short period I have employed the usual method in such cases, that of smoothing the data by combining into one average successive portions of the data having a length equal to the period to be eliminated. I have employed as the unit data 12-month means, six months apart, and centered on January 1, and July 1. From these means consecutive means of five were computed and plotted in a curve having two means per year, from which the 11-year epochs can be readily estimated to one or two tenths of a year.

These epochs are given in Table 4. The variation from Wolfer's epochs is in most cases small, only 5 out of 32 epochs showing a deviation of six months or more. The largest difference is at the maximum of 1804 where it is 1.1 years earlier than Wolfer's and the long period between the maxima of 1788 and 1804 is 15.8 years instead of 17.1 years. The probable error of the intervals maximum to maximum and minimum to minimum is ±1.2 years for the Wolfer epochs and ±1.1 years for the new epochs.

These epochs are not to be regarded as in any sense superseding the Wolfer epochs. They are merely epochs derived by the application of a different smoothing formula. The 11-year epochs of magnetic declination range referred to below were derived in the same manner, as it was desirable to completely free each series from the short-period fluctuations in order that the two series of 11-year epochs might be strictly comparable.

ANALYSIS OF MAGNETIC DATA

We are not limited, however, to solar data for evidences of the 11-year and 28-month variations. It has long been known that the 11-year variation in spottedness is closely paralleled by the variation of the diurnal inequality range of magnetic declination.

The diurnal inequality of declination for any particular month is the sequence of the residuals of the means of the hourly values of declinations from the monthly mean declination. On the average of quiet days in the summer months there is a smooth progression of the residuals with extreme values around 7 to 8 a. m. and 1 to 2 p. m.

The 11-year epochs of maxima and minima.—In the year 1852 Wolf, Sabine, and Gautier published nearly simultaneously their discovery of a direct and parallel relation between the solar spottedness and the mean daily range of magnetic declination. Wolf derived a formula connecting yearly values of magnetic range, R, and sunspot frequency, S, by a relation $R=a+bS$, in which a and b are constants to be determined from the observed values of R and S. He compiled in his Astronomische Mitteilungen all available magnetic data and showed that this close relation has existed since 1780, and derived epochs of maximum and minimum range. Making due allowance for accidental deviations in individual cases, the coincidence of the 11-year epochs of the two phenomena is so close that the magnetic data can be regarded as coequal with solar spottedness as an index of solar activity.

I have made a new determination of the 11-year epochs of maximum and minimum declination range, using for this purpose the table compiled by Fritz 6 which gives all available values of yearly ranges from 1834 to 1877 for numerous stations. Most of the data previous to 1873 are based on eye observations at hours selected to yield approximately the extremes, usually 8 a. m. and 2 p. m. If fixed hours are consistently adhered to, the epochs derived therefrom are quite as reliable as those from recording instruments. Numerous sources of error, however, tend to render the series at certain stations non-

homogeneous in many cases—change in instruments and hours of observations, spider webs or fungous growths causing a restricted range, etc.—but by averaging the results for a number of stations the desired accuracy is attained.

For the derivation of epochs subsequent to 1873 practically all published records from stations having magnetographs have been examined. Monthly mean values of the range between the minimum around sunrise and the early afternoon maximum have been tabulated for these stations, and the data are therefore, comparable with the Fritz yearly ranges. It is believed that higher correlations between the sunspot relative numbers and magnetic data will result from the employment of magnetic ranges thus derived than from the 24-hour ranges which are commonly regarded by magneticians as the diurnal inequality range.

The method of deriving the magnetic epochs is in all respects similar to the one employed for the derivation of the epochs of sunspot maxima and minima. Yearly ranges around the epochs for a number of stations were averaged and either by simple inspection of the data in the case of a single well-marked crest or hollow or guided by a preliminary smoothing, epochs to the nearest quarter of a year were selected.

Table 4 gives the epochs of maximum and minimum diurnal inequality range. The average deviation from the sunspot epochs is + 0.08 year, the solar epochs preceding the magnetic epochs.

The 28-month epochs.—As stated above there are secondary fluctuations superposed upon the primary 11-year variation in the diurnal inequality range. Employing on the monthly ranges the same smoothing process by which Wolfer derives his smoothed relative numbers, the annual variation and periods of shorter length are eliminated. The early numbers of Wolf's Astronomische Mitteilungen contain such smoothed monthly values of declination range for 6 to 10 stations in Europe for each year from 1839 to 1890. I have plotted these values and derived independently for each curve the 28-month epochs of maxima and minima. For various reasons above mentioned there are minor divergencies between the curves, but there is little difficulty in determining by a comparison of all the curves mean epochs within an accuracy of one or two tenths of a year, due consideration being given to the effect of the large amplitude of the 11-year variation in displacing the position of the epochs. Most of Wolfer's data were based on eye observations but the ranges were derived from hours around 8 a. m. and 1 p. m. and the epochs therefore are approximately those of the diurnal inequality ranges and may be regarded as substantially accurate.

The only available series of hourly observations from which the diurnal inequality range, 8 a. m. to 1 p. m., can be derived previous to 1870 is that at St. Petersburg from 1841 to 1862. Greenwich 24-hour ranges are available from 1841 but comparison with other stations shows numerous irregularities in the series which renders them unsuitable for this purpose.

I have tabulated the monthly diurnal inequality ranges for the following stations: Greenwich, 1868–1925; Pavlovsk, 1873–1908; Tiflis, 1870–1908; Paris, 1883–1925; Potsdam, 1890–1924; Pola, 1886–1915; San Fernando, 1880–1924; Bombay, 1871–1905; Mauritius, 1883–1909 (broken); Cheltenham, 1901–1924; Sitka, 1902–1924.

For each of these series I have computed two 12-month means per year, centered January 1 and July 1. These values were smoothed by moving averages of five terms to eliminate the short variation. Residuals of these smoothed values from the actual values give the 28-month variation freed from the 11-year variation. From graphs of these residuals epochs of maxima and minima were read off to the nearest quarter of a year. Figure 4 shows a number of these graphs. Table 5 contains these epochs with the corresponding epochs of Wolfer's relative sunspot numbers. The differences between the two series range between +1.8 year and −1.0 year. The mode is 0.0, the probable error is ±0.54 year and 57 per cent of the intervals are 0.25 year or less. The mean is +0.068 year, the solar epochs preceding the magnetic epochs. This lag in the magnetic epochs is apparently real since it is the average of 75 cases, which seems a sufficiently large number to insure elimination of accidental errors in the individual epochs.

These magnetic epochs have been derived almost exclusively from records in the northern hemisphere. Since the diurnal inequality range at the winter solstice is very small at stations in high latitudes, the variations are obviously mainly determined by the ranges of the warmer months. Data from the southern hemisphere should be available to obtain variations in December and adjacent months to supplement those in the other hemisphere. This is the chief reason for the occasional large deviations from the sunspot epochs. Then, too, the latter epochs are subject to much uncertainty for various reasons. The two series of epochs, however, satisfactorily agree in the long run and with more data available and in a more homogeneous form they should agree closely at all times. Magnetic data give independent evidence of great value for the determination of the 28-month variation and should be available to students as early as possible.

THE 28-MONTH PERIOD IN THE UNITED STATES TEMPERATURES

The epochs of maximum and minimum temperature for the United States are given in Table 2. They are substantially as published in my earlier paper on the 28-month period. A curve of the smoothed intervals between consecutive maxima or minima is shown as curve 4 in Figure 3. There is evident a tendency to an 11-year variation in the length of the period; long and short periods occur about four years after the Wolfer epochs of minima and maxima, respectively. The 11-year epochs of long and short intervals are given in Table 3.

The association of minima of temperature with the epochs of maximum north H. L. is regarded as the true relationship. This is based on statistical and other considerations and will be discussed below. Table 2 columns 15, 16 contains the lag of the temperature epochs relative to the H. L. epochs. These lags smoothed are shown as curve 5, Figure 3. The average lag is 1 year with, however, a systematic variation in length having a period of 11 years. Long and short lags occur about five years after the Wolfer epochs of minima and maxima, respectively.

When the epochs of temperature were published the H. L. epochs from 1855 to 1875 were not known. The reality of these latter epochs is confirmed by the same consistent relationship between them and the H. L. epochs that has characterized the two series of epochs from 1875 to 1925 and which was graphically shown in Figure 1 of my earlier paper. (2.)

Relation of short-period variations in temperature to solar conditions.—The question arises what are the par-

ticular solar phenemona with which the terrestrial temperature variations are most closely associated? Do they depend on variations in spottedness or upon the variations in the position of the spotted areas? The 11-year temperature variation seems to be closely related to the variations in spottedness since opposite phases very nearly, synchronize the phase differences being of the order of a few months only, when long records are analyzed.

On the other hand the 28-month variation in temperature seems to depend upon the position of spots rather than their magnitude or frequency. This is apparently shown by an analysis of the lag of the temperature epochs relative to various solar phases. The lag of the temperature epochs from the H. L. epochs, regarding epochs of temperature minima as associated with epochs of maximum north H. L., is shown in Table 2, columns 15, 16. The average of these is 1 year, the mean deviation, 0.35 year, and the mean variability 0.27 year. Incidentally, attention should be directed to the very low Goutereau ratio (cf. MONTHLY WEATHER REVIEW September, 1924, pp. 432, 441), which is 0.77, while for unrelated numbers it is 1.41. This small ratio indicates a highly systematic variation in the values of the lag, as is evident from the graph (5) in Figure 3.

When the lags of the temperature epochs from the sunspot epochs are analyzed, we have for the lag based on like phases, average 0.9 year, mean deviation 0.61 year, mean variability 0.32 year. In this case the Goutereau ratio is only 0.52. For the lag based on unlike phases, or the lag from maximum spottedness to minimum temperature we have, average 2.14 years, mean deviation 0.59 year, and mean variability 0.33 year. The fact that the scatter of the values of the lag is so much smaller when the H. L. epochs are used seems to indicate that in some way the temperature depends more on the position of the spots than upon their magnitude. At any rate, the forecasting of temperature variations from solar variations will show a greater probability of verification when based on the H. L. rather than on the S. S. epochs.

That the causal relation is between the maximum north H. L. and the immediately following tempeature minimum is shown by the greater mean deviation of the lags with other combinations. The lag from the maximum north H. L. epochs to the immediately following temperature minima has, as above stated a mean deviation of 0.35 year. From the same epochs to the next following temperature maxima the lag has a mean deviation of 0.40, while the lag to the second following temperature minimum has a mean deviation of 0.46 year. It seems reasonable that the causal relation is with the combination having the least mean deviation of the lag. The number of variates, 100, is sufficiently large to justify confidence in these values.

It is noteworthy that the mean deviation of the lag from the H. L. epochs is much less for the temperature epochs than for the S. S. epochs, which is probably due to the relatively low correlation between the spottedness of the two hemispheres referred to above.

Having presented the main results of the investigation a discussion of their significance will now be given and certain criticisms answered.

The point at issue is, of course, the reality of the 28-month epochs in Table 2. The author's paper (2) on the 28-month period has been criticized by some meteorologists seemingly from failure properly to apprehend and appreciate the significance and evidential value of the results obtained from the simple statistical methods there employed. It is charged that the selection of epochs from graphs must be on the basis of a minimum amplitude or some such criterion otherwise the selection must be influenced by one's desires. By reference to the curves of H. L. and S. S. residuals it will be seen that the employment of a criterion based on amplitude alone would be utterly futile. Such a method would be effective only when the amplitude is fairly uniform as in the case of the 11-year variation in sunspots, where amplitude is the only criterion necessary. The 28-month variation unfortunately is much less obvious and other criteria must be resorted to in order that the selection of epochs shall not be merely arbitrary.

To many readers the methods employed by me may seem loose and inefficient. Walker (4), in a discussion of my previous paper on the 28-month period in weather conditions deplores a "departure from definite and reliable methods based on Fourier analysis and in their place we have" (quoting words from my paper) "an empirical method based largely upon careful examination of curves drawn free hand through plotted data or derived by means of smoothing formulæ." He points out that the selection of epochs of maxima and minima, either from smoothed or unsmoothed curves, must be made on the basis of some definite criterion, "otherwise our selection must be influenced by our desires." Finally, in discussing the changing lengths, which range from 1.8 to 3 years, of the 28-month period shown by me to characterize the pressure at Portland, Oreg., he says:

> Now if surges of 1.8 years and of 3 years are treated as variations of a 28-month period, what limit is there to such variation, and why should we speak of such surges as constituting "periods"? The word "period" has hitherto had a definite meaning in physical mathematics and it will tend to confusion if it has to bear also a second meaning.

While recognizing the abstract superiority of rigorous methods like the periodogram analysis, and indeed the self-correlation of a series of quantities after they have been shifted successively one, two, three, etc., time steps with reference to each other, nevertheless these analytically similar or equivalent rigorous methods are peculiarly adapted to periodicities which are of uniform length, and their application has in general failed to give definite indications of periodicity in meteorological and solar data. This is a result to be expected if real periods exist which vary considerably in length, especially when many repetitions of the irregular periods are comprised in the computations. Moreover, when the results secured by both the rigorous and the empirical methods are fairly interpreted the findings are not seriously in conflict.

In his paper Walker applied the self-correlation method to pressures at Darwin which he considers are representative of a "wide-spread belief * * * of a 3 to 3½ years' period in the region extending from Java to N. Australia." This method was employed by me in my paper on the 28-month period, using an abridged method of correlation based on variate differences, which, however, when the number of variates is large, yields results essentially the same as by the usual Pearsonian method. Walker correlates the Darwin pressure data for each season and the entire data and finds for the latter a broad band of positive correlation coefficients from 2½ to 4½ years with the maximum coefficient $+0.26 \pm 0.05$ at approximately 3⅛ years. The reality of the period is apparently indicated by his criterion based on the probable maximum coefficient. The separate seasons, however, show a variation in the time interval which gives the

maximum positive coefficient. For December to February it is 2⅞; for March to May and September to November, 3⅛; and for June to August, 3⅜ years. The average of the four seasons is 3⅛ years, which agrees with the interval given by the entire data.

There is therefore a variation of one-half year in the apparent length of the period when the data are correlated for the separate seasons. This shows that when rigorous methods are applied to periodicities which vary in length the results may differ considerably when the data are correlated in various ways, a further illustration that all such results are to be interpreted with much caution.

The reality of this recurrence seems highly probable from a consideration of the various criteria. Its length, however, can be only approximately derived by such rigorous methods as the periodogram analysis and self-correlation. This is well illustrated by the sunspot period, which is 11.13 years when derived by a least square computation from the epochs of maxima and minima. The periodogram analysis, however, gives the maximum amplitude at about 11.4 years, based on the curve from 1750 to 1900. Similarly the method of self-correlation indicates for the Darwin and Batavia pressures a probable recurrence of 3 or 3⅛ years in length, while the average length derived by my methods from 1882 to 1920, according to my table of Batavia epochs, is 32.7 months, or nearly 2¾ years. The length of a variable period can be best obtained by first determining the epochs of maxima and minima.

To show that the method of correlation used by me gives essentially the same results as to length of period as the ordinary method used by Walker, I have computed the coefficients for the mean half-yearly pressures at Darwin for the same interval of time, 1882–1923, with the following results. The number of variates is 84.

Time steps, years	0.0	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5
Correlation: r Clough	+1.00	+0.30	−0.47	−0.43	−0.47	+0.31	+0.45	+0.31	−0.46	−0.38
Walker	-------	-------	-------	−.10	−.12	+.12	+.24	+.16	+.04	0

The sequence of the coefficients indicates a recurrence of 3 years as the most probable interval, which agrees closely with Walker's results, even though the coefficients differ numerically.

With reference to a criterion for the selection of epochs the writer believes this demand is satisfied by the great care exercised before the final epochs are adopted. Unfortunately the period is not clearly defined in any one curve, and it is necessary to compare curves of various elements at the same station as well as curves from neighboring stations, that the epochs may be consistent. This process was carefully explained in my paper on the 28-month period and seems to be a reasonable anticipation of and answer to Mr. Walker's objections. The explanation is quoted as follows:

> The observations at Batavia were studied in considerable detail. Three means per year were employed, each four-month period receiving an appropriate correction for annual variation. Curves were drawn for four elements, viz, pressure, mean maximum temperature, mean minimum temperature, and rainfall. By comparison of these four curves it was possible to determine definitive epochs since 1866. The epochs of maximum and minimum pressure coincide closely with the epochs of minimum and maximum frequency, respectively, of rainfall. The epochs of mean maximum temperature follow similar phases of the pressure by about four months as an average. The epochs of mean minimum temperature follow by a few months the epochs of the mean maximum temperature. The fluctuations of pressure are entirely representative of such fluctuations for the whole Indian Ocean region, including India, Australia, and Mauritius.

Curves, therefore, for four elements at the station were compared and epochs so selected as to insure consistency in them as regards the mentioned interrelations and lags, which are obvious from simple inspection of the curves. Furthermore, curves for many other stations in the Indian Ocean region were examined before definitive epochs were finally adopted. There are many factors involved in meteorological variations and it is only by a careful comparison of numerous curves for different stations that the significant and real features emerge from the accidental features which may partially obscure them in the individual curves. An illustration is the anomalous depression in the maximum temperature curve at Batavia in the latter part of 1883 which is plausibly due to the Krakatoa eruption.

Again, the epochs of pressure and temperature for Europe were selected so that for each epoch of pressure in southwestern Europe there was a corresponding epoch of temperature with like phase in northern Europe. This relation is a necessary consequence of the association of high temperature with winds having a southerly component and vice versa.

Taking up finally the application of the word "period" to recurrences at intervals which vary in such ratios as 1.8 to 3, the writer realizes such a practice is objectionable; however, up to the present time no good substitute word has ever been proposed. Moreover, repeating a statement at an earlier place in this paper, astronomers have long been accustomed to designate as periods such irregular recurrences as that of maximum solar spottedness and the maximum brilliancy of variable stars. We may, therefore, regard this practice as an instance of a meaning inconsistent with the primary significance of a word but sanctioned by usage. The solar cycle of 11 years varies between 7 and 17 years, one-half of the intervals being less than 10 years or greater than 12 years, and the variations can not be satisfactorily explained on the basis of fortuitous causes alone. This being the case the author believes he is justified in claiming to find evidences of variability in the various solar and meteorological periods

The evidences for the reality of the results of the investigation are mainly of a statistical nature and obviously some familiarity with statistical processes and a certain amount of experience in their application to observational data is essential in order that the reader may fully appreciate the significance of the results.

The existence of the 11-year variation in various solar data is clearly obvious from the yearly means of spots, faculæ, flocculi, prominences, etc., and the mear latitude of all spots. Other data, as the mean heliographic latitude of the entire spotted area, require a preliminary smoothing to cearly disclose the 11-year variation. This, however, is an ordinary statistical procedure, similar to the method employed by Wolfer in the derivation of his smoothed monthly relative numbers.

The existence of the 28-month period, however, is not as obvious from simple inspection of a graph as is the 11-year period in a graph of the yearly relative numbers or the average latitude of spots. It is first necessary to establish by purely impersonal, rigid, statistical tests the fact that the order of sequence of the peaks and hollows of certain solar data and the most frequent interval between them differ markedly from that which would characterize them if their occurrence were perfectly fortuitous. Given the observational data, anyone employing the methods and criteria used by the writer will

necessarily obtain the same results as set forth on page 254. These results are absolutely devoid of any human element.

Tabulating the frequencies of the varying intervals between peaks and hollows of the smoothed residuals of the half-yearly means of the H. L. data we derive the most frequent interval, 2.4 years. With this datum we proceed to locate tentative epochs and draw a smooth curve, ignoring minor fluctuations. The next step is an intercomparison of two or more curves similarly derived to insure consistency between the epochs and confirm their reality, based on their a priori or statistically derived relationships.

variation averages 11 years, which is the period of variation of the spotted area, affords a substantial basis for regarding them as real.

Another significant relation is that the 28-month period in the relative numbers is shortest 0.6 year before the Wolfer epochs of maximum spottedness. A priori there would seem to be good reason for this since we should expect that at the time of maximum solar activity the various solar processes would be accelerated, and if there were short period fluctuations they would be completed in a relatively short period of time, just as un-

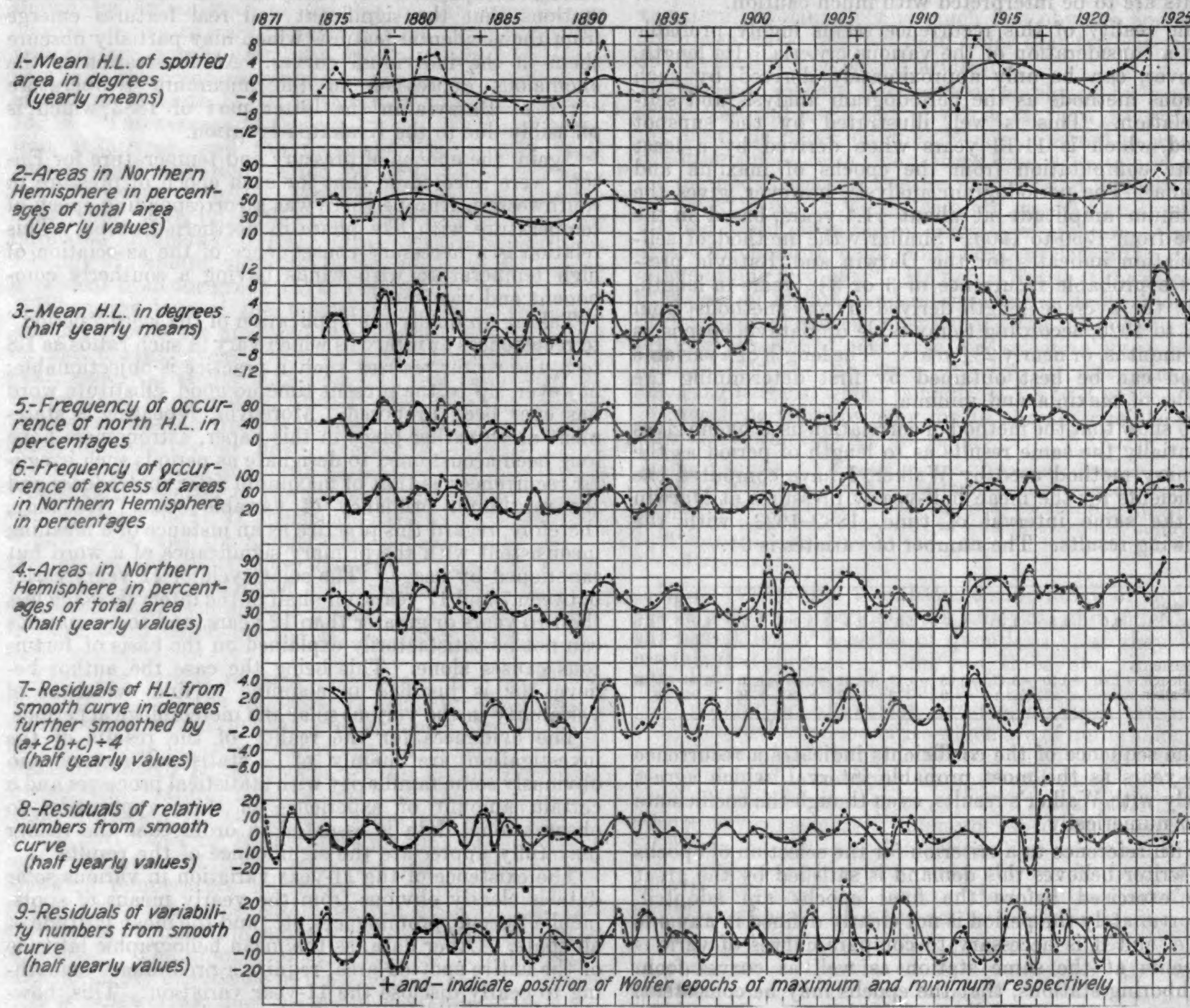

FIG. 1.—Yearly and half-yearly means of data derived from the Greenwich solar measurements and the Wolfer relative numbers, with smooth curves showing the 11-year and 28-month periods

The epochs of the H. L. and the S. S. having been selected, with of course an element of human judgment entering into them, further tests are applied in order to detect evidence of systematic tendency in them which would be wholly lacking if they were unreal. Thus the existence of an 11-year variation in the length of the period in both the H. L. and S. S. series of epochs (cf. curves (1) and (2), fig. 3) is obvious evidence that the epochs from which the period lengths are derived are as real as Wolfer's epochs. The fact that the long-period

usually intense 11-year maxima follow very soon after the preceding epoch of minimum.

It was shown in my former paper (1) that when the sunspot period is around 8 to 10 years, high relative numbers at maxima occur a few years later.

It is evident, therefore, that the real measure of solar activity is the length of the solar periodicities, short intervals being associated with maximum activity and vice versa. The amount or frequency of spottedness appears to be a result rather than an indication of activity, since

the epochs of spottedness occur 0.6 year later than the epochs of the length of the period.

A still further significant result is the well-defined 11-year variation in the lag of the S. S. relative to the H. L. epochs. (Curve (3) fig. 3.) The two series of epochs were originally derived independently of each period of solar activity, the 11-year period. Such regular systematic variations could not possibly result from data akin to random numbers which would necessarily characterize a selection of epochs based on a criterion of amplitude alone or in which a large element of human judgment or personal bias was involved.

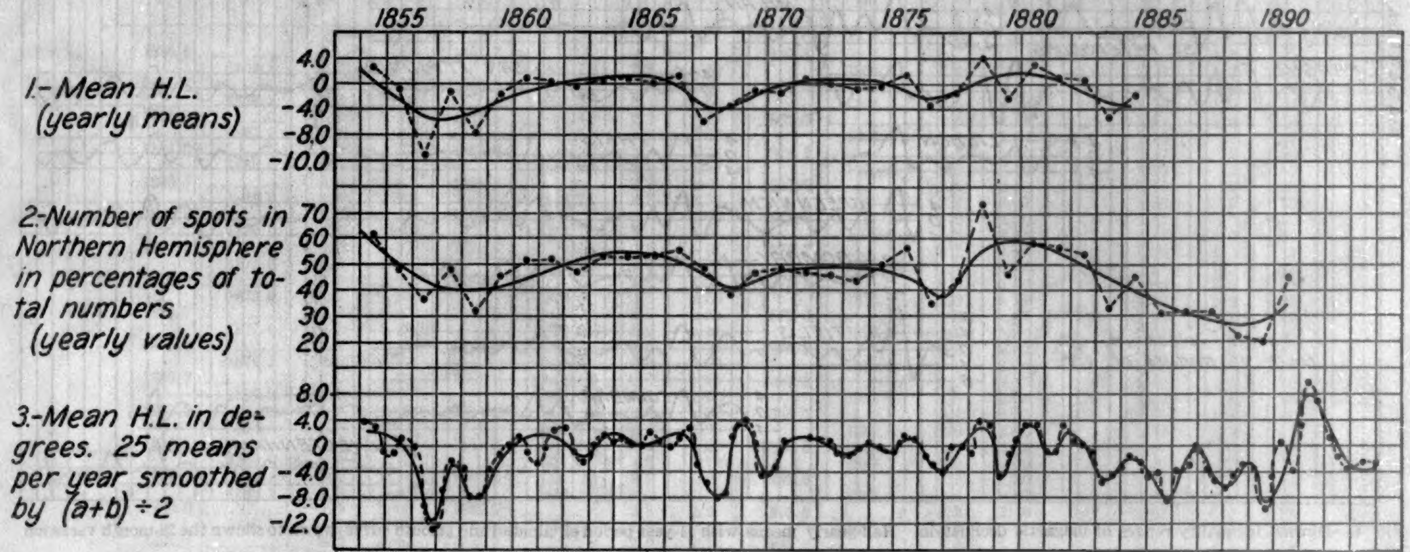

FIG. 2.—Yearly and half-yearly means of data derived from Carrington's and Spoerer's solar measurements with smooth curves showing the 11-year and 28-month periods

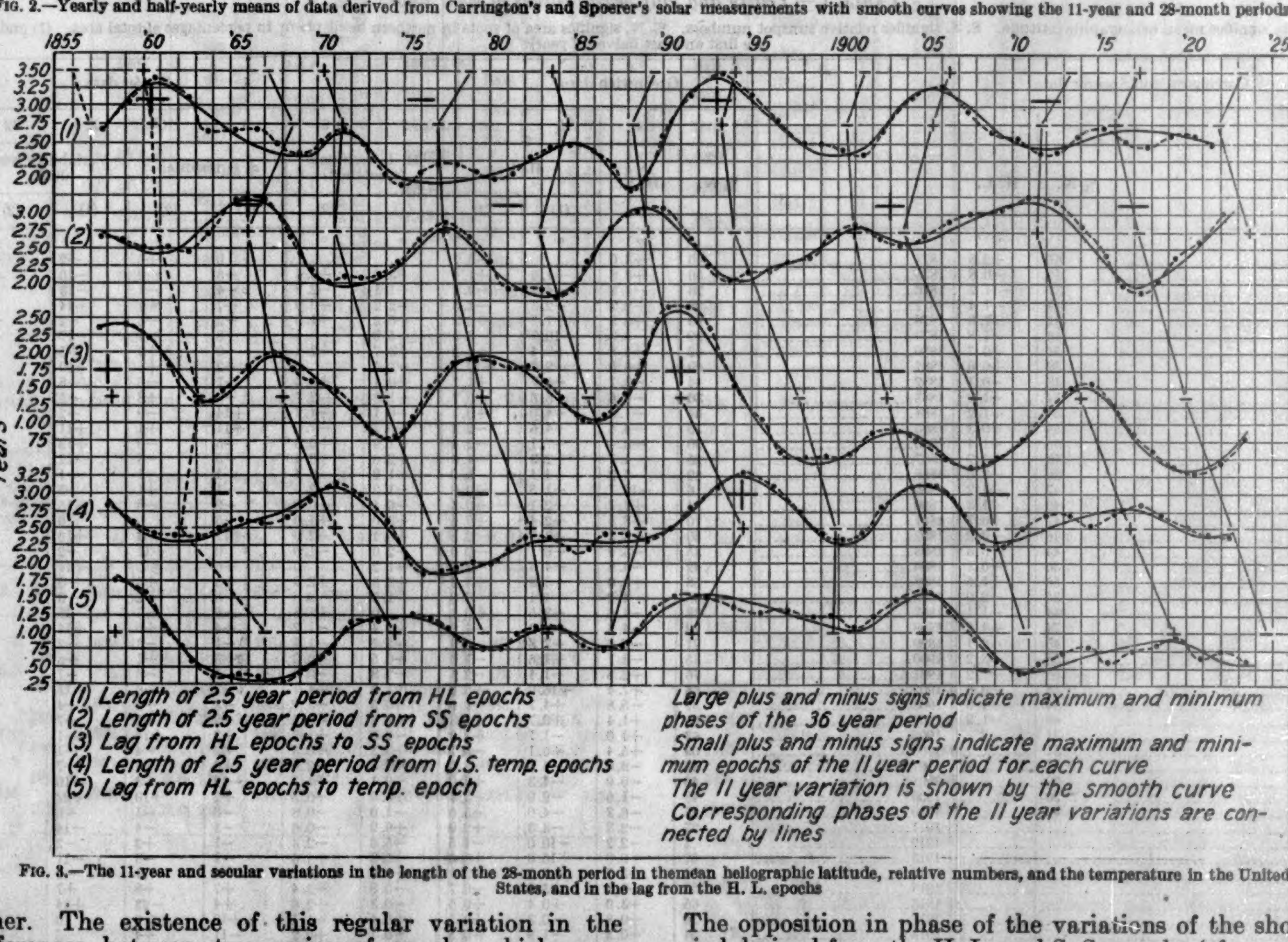

FIG. 3.—The 11-year and secular variations in the length of the 28-month period in themean heliographic latitude, relative numbers, and the temperature in the United States, and in the lag from the H. L. epochs

other. The existence of this regular variation in the differences between two series of epochs which were independently derived would seem to be utterly improbable unless the two series represented real phases of solar activity and unless the variations of the secondary fluctuations were actually conditioned by the fundamental

The opposition in phase of the variations of the short period derived from the H. L. and S. S. epochs (cf. curves (1) and (2) fig. 3) is another relation which is quite inexplicable from an apriori point of view, but its persistence over a period of 75 years again would seem to preclude any possibility of the unreality of the epochs.

Disregarding, the details of the methods used, the outstanding feature of the whole investigation is the consistency of the results obtained, *shown by the persistent appearance in the final results of the 11-year variation in Fig. 3.* Just as the meeting of two tunnel bores from opposite sides of a mountain is sufficient evidence of accuracy in the observations taken to insure correct alignment of each bore, so these consistent end results are prima facie evidence of the validity of the methods employed in their attainment.

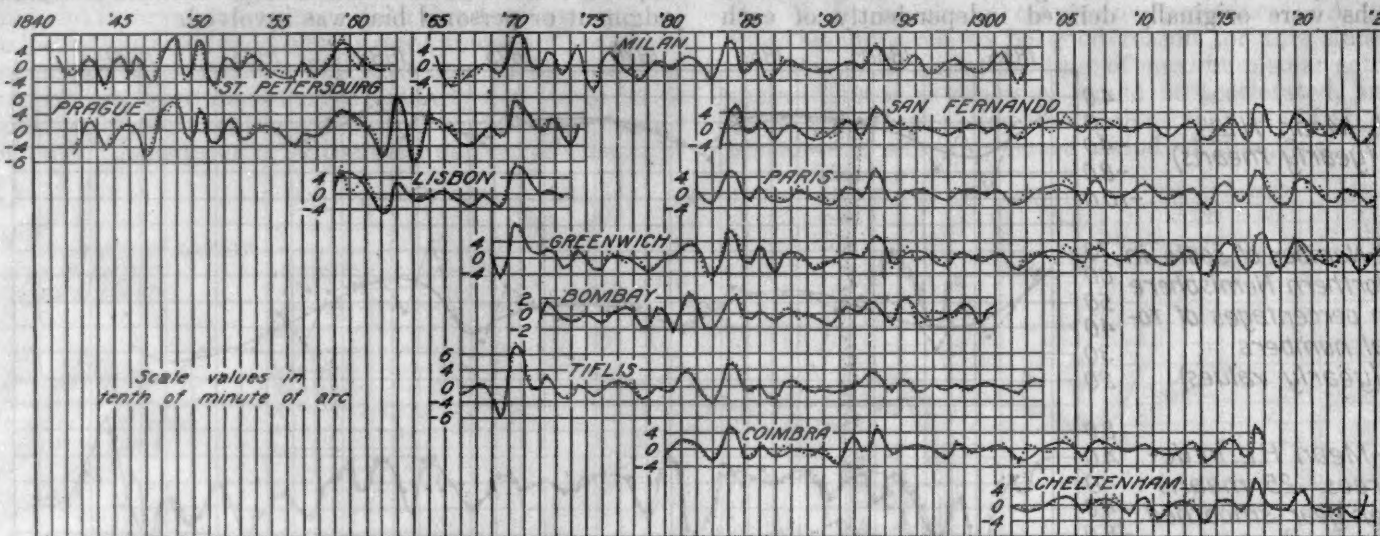

FIG. 4.—Diurnal inequality ranges of magnetic declination. Half-yearly means with 11-year period eliminated and smooth curve drawn to shown the 28-month variation

TABLE 1.—*Yearly and half yearly values of solar data*

[H. L. signifies mean heliographic latitude. S. S. signifies relative sunspot numbers. % N. signifies area of spots in northern hemisphere in percentages of total area. (1) and (2) are first and last halves of year]

Carrington and Spoerer data			Greenwich data							Wolfer data				
	1	2		3	4	5	6	7	8	9	10	11	12
	% N.	H. L.		% N.	H. L.	H. L.		H. L. residuals (smoothed)		S. S. residuals		Variability residuals	
						(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)
		°			°	°	°	°	°				
1854	61	+2.5	1874	46	−3.0	------	−3.7	------		0	+5	+2	+18
1855	49	−0.8	1875	56	+2.8	+1.6	+1.4	+3.0	+2.4	−6	−9	−10	−14
1856	37	−11.2	1876	26	−3.8	−4.1	−4.6	−1.1	−2.8	−4	−1	−13	0
1857	49	−1.4	1877	28	−2.7	−2.3	−1.6	−2.2	+0.9	+7	+1	+14	+2
1858	31	−7.8	1878	99	+6.9	+7.2	+6.2	+5.2	+1.9	−2	−5	−2	−16
1859	45	−1.8	1879	29	−9.3	−10.3	−3.3	−5.8	−3.4	−8	−7	−17	−4
1860	51	+0.7	1880	62	+4.8	+9.4	+5.2	+3.7	+2.4	−0	+3	+5	+4
1861	52	+0.6	1881	69	+6.0	−2.7	+10.7	−1.4	0	+2	+5	+10	+8
1862	48	−0.1	1882	44	−3.7	−5.7	+1.7	+0.4	+0.5	+7	−6	−8	+12
1863	54	+1.0	1883	30	−6.6	−5.6	−6.9	−1.6	−2.7	−6	+8	−5	+7
1864	54	+1.2	1884	44	−1.8	−4.0	+0.1	−0.1	+1.7	+14	−9	+2	−7
1865	54	+0.3	1885	35	−4.4	−4.6	−2.2	+0.7	−1.0	+11	+1	+11	+1
1866	55	+1.4	1886	20	−6.4	−7.1	−2.4	−1.9	+0.6	+5	−9	+13	−14
1867	48	−5.7	1887	25	−4.1	+2.3	−4.3	+2.6	+0.4	−5	−3	−12	+8
1868	39	−3.6	1888	22	−4.2	−4.4	−5.0	−1.2	−0.4	−1	−1	+1	−2
1869	47	−1.2	1889	6	−10.7	−1.5	−10.0	−1.2	−2.5	−1	+1	−5	−2
1870	49	−1.3	1890	54	+1.7	+2.1	−0.3	−0.5	+0.9	−9	−8	−15	−8
1871	47	+0.7	1891	70	+8.5	+2.4	+9.4	+3.0	+4.0	−5	0	0	+1
1872	46	+0.2	1892	50	−3.3	−3.7	−2.8	+0.1	−2.6	+11	+4	+16	−4
1873	44	−0.3	1893	35	−3.9	−6.1	−2.0	−2.0	−1.0	0	+11	+2	+16
1874	50	−0.1	1894	42	−3.8	−4.3	−2.3	−1.2	0	+6	0	+11	−8
1875	56	+1.6	1895	58	+3.0	+3.3	+3.2	+3.3	+2.9	+3	+3	+5	+1
1876	35	−2.9	1896	38	−4.2	−4.1	−6.0	−1.2	−2.8	−6	−2	+3	0
1877	44	−1.1	1897	38	−1.6	−3.5	+0.1	0	+1.8	−8	−3	−13	−4
1878	74	+4.2	1898	29	−4.8	−6.0	−4.7	+0.4	−1.2	+4	+6	+14	+3
1879	46	−2.1	1899	21	−7.0	−7.8	−6.3	−2.2	−1.3	−1	−3	−2	−3
1880	58	+3.2	1900	35	−3.1	−1.6	−1.6	+0.5	−0.2	+3	−1	+8	+2
1881	56	+1.2	1901	76	+2.8	−1.4	−2.4	−2.8	−0.3	−1	−3	−7	−10
1882	54	+0.6	1902	68	+7.4	+16.0	+6.0	+5.6	+4.7	−3	−6	−11	−12
1883	34	−4.8	1903	39	−5.8	+4.7	−4.0	−0.5	−3.1	−3	+5	+4	+18
1884	45	−1.9	1904	55	+1.4	+0.7	+1.3	−1.6	−0.6	−2	+1	−7	−5
1885	31	------	1905	63	+1.6	−1.7	+3.3	−0.8	+1.7	+3	+14	−1	+34
1886	31	------	1906	69	+5.4	+6.1	−0.1	+3.3	+0.3	−6	−4	−1	−10
1887	31	------	1907	45	−3.0	−4.5	−2.0	−2.3	−2.0	+6	+4	+7	−10
1888	22	------	1908	45	−0.9	−4.3	+2.0	−0.1	+1.7	−12	+8	−10	+17
1889	20	------	1909	43	−1.6	−2.9	−3.3	+0.9	−0.5	+2	+10	+22	+14
1890	45	------	1910	25	−6.3	−4.0	−5.6	−1.0	−0.8	−6	−1	−6	−1
1891	------	------	1911	27	−2.3	−3.3	+0.0	+0.9	−0.6	−4	−4	−14	−8
1892	------	------	1912	3	−2.2	−10.0	−4.5	−5.6	−2.3	−1	+2	−2	+5
1893	------	------	1913	67	+0.8	+15.0	+6.6	+5.3	+4.6	−1	−3	−11	−14
1894	------	------	1914	65	+5.7	+7.1	+3.1	+1.0	−0.2	−6	−11	−5	−14
1895	------	------	1915	54	+0.8	+5.2	−0.7	−0.8	−2.4	+7	+8	+7	+21
1896	------	------	1916	65	+3.9	+0.4	+9.6	−0.3	+2.6	+4	−23	+14	−19
1897	------	------	1917	56	+0.8	−0.3	+0.5	+0.4	−1.1	+10	+3.3	0	+27
1898	------	------	1918	54	+0.3	+1.9	−0.5	−0.1	+0.2	−11	+4	−5	+15
1899	------	------	1919	53	−0.3	+0.6	−2.4	−0.1	−0.4	+6	−3	0	−5
1900	------	------	1920	34	−2.8	−0.3	−3.1	−0.8	−1.3	−2	−6	+10	−17
1901	------	------	1921	62	+1.1	−1.0	+3.0	−0.4	+2.1	−1	0	+5	+1
1902	------	------	1922	64	+3.2	+4.0	−3.6	+1.2	−1.8	+3	−4	+4	−10
1903	------	------	1923	60	+1.3	+3.3	−1.7	------	------	−5	−4	−2	−10
1904	------	------	1924	84	+14.5	+11.8	+13.1	------	------	−4	−3	−24	0
1905	------	------	1925	62	+5.6	+6.3	+3.0	------	------	−10	+11	------	------

TABLE 2.—*The 28-month epochs in solar data and United States temperature and the intervals and lags between the epochs, actual and smoothed*

H. L. epochs				S. S. epochs				U. S. temp. epochs				Lags			
Max.	Min.	Intervals		Max.	Min.	Intervals		Min.	Max.	Intervals		H. L. to S. S.		H. L. to temp.	
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1855.0				1857.7				1856.5				2.7		1.5	
	1856.7	2.7			1858.7	2.3	2.60		1858.2	3.0		2.0	2.33	1.7	1.67
1857.7		2.0	2.67	1860.0		2.8	2.51	1859.5		2.3	2.60	2.3	2.37	1.8	1.77
	1858.7	3.3	3.03		1861.5	2.5	2.50		1860.5	2.5	2.43	2.8	2.20	1.8	1.53
1861.0		3.8	3.37	1862.5		2.2	2.47	1862.0		2.5	2.40	1.5	1.83	1.0	1.10
	1862.5	3.0	3.10		1863.7	2.7	2.73		1863.0	2.2	2.40	1.2	1.30	.5	.57
1864.0		2.5	2.67	1865.2		3.3	3.17	1864.2		2.5	2.50	1.2	1.47	.2	.40
	1865.0	2.5	2.67		1867.0	3.5	3.17		1865.5	2.8	2.60	2.0	1.80	.5	.40
1866.5		3.0	2.67	1868.7		2.7	2.67	1867.0		2.5	2.60	2.2	1.97	.5	.33
	1868.0	2.5	2.50		1869.7	1.8	2.17		1868.0	2.5	2.67	1.7	1.80	.0	.33
1869.0		2.0	2.33	1870.5		2.0	2.00	1869.5		3.0	2.90	1.5	1.63	.5	.50
	1870.0	2.5	2.50		1871.7	2.2	2.07		1871.0	3.2	3.13	1.7	1.47	1.0	.73
1871.5		3.0	2.67	1872.7		2.0	2.07	1872.7		3.2	2.97	1.2	1.20	1.2	1.13
	1873.0	2.5	2.50		1873.7	2.0	2.10		1874.2	2.5	2.57	.7	.87	1.2	1.20
1874.0		2.0	2.07	1874.7		2.3	2.27	1875.2		2.0	2.10	.7	.80	1.2	1.20
	1875.0	1.7	1.90		1876.0	2.5	2.60		1876.2	1.8	1.87	1.0	1.07	1.2	1.23
1875.7		2.0	2.07	1877.2		3.0	2.83	1877.0		1.8	1.87	1.5	1.50	1.3	1.17
	1877.0	2.5	2.23		1879.0	3.0	2.67		1878.0	2.0	1.90	2.0	1.83	1.0	1.03
1878.2		2.2	2.23	1880.2		2.0	2.27	1879.0		2.0	2.00	2.0	1.93	.8	.87
	1879.2	2.0	2.07		1881.0	1.8	1.93		1880.0	2.0	2.00	1.8	1.87	.8	.80
1880.2		2.0	2.00	1882.0		2.0	1.93	1881.0		2.0	2.17	1.8	1.80	.8	.80
	1881.2	2.0	2.10		1883.0	2.0	1.90		1882.0	2.5	2.33	1.8	1.80	.8	.97
1882.2		2.3	2.27	1884.0		1.7	1.80	1883.5		2.5	2.33	1.8	1.60	1.3	1.03
	1883.5	2.5	2.43		1884.7	1.7	1.90		1884.5	2.0	2.23	1.2	1.33	1.0	1.03
1884.7		2.5	2.50	1885.7		2.3	2.27	1885.5		2.2	2.23	1.0	1.07	.8	.83
	1886.0	2.5	2.40		1887.0	2.8	2.77		1886.7	2.5	2.40	1.0	1.10	.7	.77
1887.2		2.2	2.17	1888.5		3.2	3.07	1888.0		2.5	2.40	1.3	1.43	.8	.83
	1888.2	1.8	1.83		1890.2	3.2	3.07		1889.2	2.2	2.23	2.0	2.00	1.0	1.00
1889.0		1.5	2.00	1891.7		2.8	2.67	1890.2		2.3	2.50	2.7	2.67	1.2	1.33
	1889.7	2.7	2.57		1893.0	2.0	2.27		1891.5	3.0	2.77	3.3	2.67	1.8	1.50
1891.7		3.5	3.17	1893.7		2.0	2.10	1893.2		3.0	3.10	2.0	2.37	1.5	1.53
	1893.2	3.5	3.50		1895.0	2.3	2.17		1894.5	3.3	3.27	1.8	1.53	1.3	1.37
1895.2		3.5	3.17	1896.0		2.2	2.23	1896.5		3.5	3.10	.8	1.03	1.3	1.30
	1896.7	2.5	2.83		1897.2	2.2	2.30		1898.0	2.5	2.73	.5	.60	1.3	1.30
1897.7		2.5	2.50	1898.2		2.5	2.40	1899.0		2.2	2.40	.5	.50	1.3	1.20
	1899.2	2.5	2.50		1899.7	2.5	2.67		1900.2	2.5	2.33	.5	.50	1.0	1.20
1900.2		2.5	2.43	1900.7		3.0	2.83	1901.5		2.3	2.43	.5	.60	1.3	1.03
	1901.7	2.3	2.37		1902.7	3.0	2.67		1902.5	2.5	2.77	1.0	.83	.8	1.20
1902.5		2.3	2.70	1903.7		2.0	2.60	1904.0		3.5	3.07	1.2	.90	1.5	1.43
	1904.0	3.5	3.17		1904.7	2.8	2.70		1906.0	3.2	3.07	.7	.80	2.0	1.57
1906.0		3.7	3.30	1906.5		3.3	2.93	1907.2		2.5	2.67	.5	.50	1.2	1.33
	1907.7	2.7	2.97		1908.0	2.7	3.00		1908.5	2.3	2.27	.3	.43	.8	.93
1908.7		2.5	2.73	1909.2		3.0	3.07	1909.5		2.0	2.27	.5	.53	.8	.63
	1910.2	3.0	2.60		1911.0	3.5	3.23		1910.5	2.5	2.50	.8	.77	.3	.47
1911.7		2.3	2.43	1912.7		3.2	3.17	1912.0		3.0	2.67	1.0	1.17	.3	.53
	1912.5	2.0	2.43		1914.2	2.8	2.83		1913.5	2.5	2.67	1.7	1.50	1.0	.70
1913.7		3.0	2.67	1915.5		2.5	2.43	1914.5		2.5	2.59	1.8	1.57	.8	.77
	1915.5	3.0	2.73		1916.7	2.0	2.00		1916.0	2.7	2.73	1.2	1.27	.5	.60
1916.7		2.2	2.57	1917.5		1.5	1.90	1917.2		3.0	2.83	.8	.83	.5	.77
	1917.7	2.5	2.50		1918.2	2.2	2.07		1919.0	2.8	2.67	.5	.60	1.3	.87
1919.2		2.8	2.70	1919.7		2.5	2.40	1920.0		2.2	2.50	.5	.40	.8	.93
	1920.5	2.8	2.60		1920.7	2.5	2.60		1921.2	2.5	2.40	.2	.30	.7	.67
1922.0		2.2	2.50	1922.2		3.0	3.00	1922.5		2.5	2.40	.2	.43	.5	.73
	1922.7	2.5			1923.7	3.5			1923.7	2.2		1.0	.80	1.0	.57
1924.5				1925.7				1924.7				1.2		.2	

TABLE 3.—*Epochs of the 11-year variation in the lengths of the 28-month period and in the lags*

Wolfer's epochs		Length of 28-month period						Lag			
		H. L.		S. S.		U. S. temp.		H. L. to S. S.		H. L. to U. S. temp.	
Max.	Min.	Long	Short	Long	Short	Long	Short	Long	Short	Long	Short
1860.1		1860.5			1861.0		1862.5		1863.2		1866.0
	1867.2		1868.5	1866.0		1871.0		1868.0		1874.0	
1870.6		1871.5			1871.0		1876.7		1873.7		1879.5
	1878.9		1877.5	1877.5		1882.5		1879.5		1883.5	
1883.9		1884.5			1883.0		1889.0		1885.7		1887.0
	1889.6		1888.5	1889.2		1894.5		1891.2		1891.5	
1894.1		1893.2			1894.2		1900.0		1898.0		1900.0
	1901.7		1900.5	1901.0		1905.0		1903.0		1905.0	
1906.4		1905.2			1904.0		1909.0		1908.0		1911.0
	1913.6		1912.0	1911.5		1917.0		1914.0		1919.2	
1917.6		1916.0			1917.5		1923.0		1920.5		1924.5
	1923.6		1922.0	1923.7							

TABLE 4.—*New epochs of 11-year variation in relative numbers and intervals between epochs*

Maxima	Minima	Intervals		Maxima	Minima	Intervals		Epochs of magnetic declination range	
		(1)	(2)			(1)	(2)	Maxima	Minima
1750.3				1837.3		9.8	9.6	1837.7	
	1755.5	11.0	11.2		1843.6	11.2	10.9		1843.8
1761.3		10.7	11.3	1848.5		12.5	12.5	1848.8	
	1766.2	8.7	8.2		1856.1	11.8	12.0		1856.3
1770.0		9.3	9.0	1860.3		10.9	11.2	1859.9	
	1775.5	8.6	8.7		1867.0	10.7	10.5		1867.0
1778.6		8.9	9.2	1871.0		11.6	11.7	1871.2	
	1784.4	9.7	9.7		1878.6	12.7	13.3		1878.5
1788.3		14.2	13.6	1883.7		10.7	10.7	1884.0	
	1798.6	15.8	17.1		1889.3	10.1	10.2		1889.5
1804.1		12.1	12.3	1893.8		12.3	12.1	1893.6	
	1810.7	12.7	11.2		1901.6	12.8	12.3		1901.8
1816.8		12.3	12.7	1906.6		11.3	11.9	1906.5	
	1823.0	12.9	13.5		1912.9	11.3	11.2		1913.0
1829.7		10.8	10.6	1917.9		10.5	10.0	1917.7	
	1833.8	7.6	7.3		1923.4				1923.7

[1] Intervals from new epochs. [2] Intervals from old epochs.

TABLE 5.—*Sun spot and magnetic epochs, 28-month period*

Sun spot		Magnetic		Sun spot		Magnetic	
Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.
1837.0	1838.2	1836.5	1837.5	1880.2	1881.0	1879.2	1880.2
1839.5	1840.5	1838.7	1839.7	1882.0	1883.0	1881.7	1882.7
1841.2	1842.0	1841.0	1842.2	1884.0	1884.7	1884.0	1885.0
1842.7	1844.0	1843.2	1844.2	1885.7	1887.0	1885.7	1887.0
1845.2	1845.7	1845.2	1845.7	1888.5	1890.2	1888.0	1889.5
1846.7	1847.2	1846.7	1847.2	1891.7	1893.0	1891.2	1892.5
1848.5	1849.5	1848.7	1849.5	1893.7	1895.0	1893.5	1894.5
1850.0	1851.5	1850.5	1851.5	1896.0	1897.2	1895.7	1897.7
1852.2	1853.7	1852.5	1853.5	1898.2	1899.7	1898.7	1900.5
1854.7	1856.2	1854.7	1856.2	1900.7	1902.7	1901.5	1902.5
1857.7	1858.7	1857.5	1858.7	1903.7	1904.7	1904.7	1906.5
1860.0	1861.5	1860.0	1861.5	1906.5	1908.0	1907.5	1909.5
1862.5	1863.7	1863.0	1864.2	1909.2	1911.0	1910.2	1912.0
1865.2	1867.0	1865.5	1867.2	1912.7	1914.2	1913.2	1914.2
1868.7	1869.7	1868.7	1869.7	1915.5	1916.7	1915.7	1916.5
1870.5	1871.7	1870.7	1871.7	1917.5	1918.2	1917.7	1919.2
1872.7	1873.7	1872.7	1873.5	1919.7	1920.7	1920.0	1921.5
1874.7	1876.0	1874.5	1875.5	1922.2	1923.7	1922.7	1924.0
1877.2	1879.0	1876.7	1878.0	1925.7		1925.7	

LITERATURE CITED

(1) CLOUGH, H. W.
1905. Synchronous variations in solar and terrestrial phenomena. Astroph. Jour. 22: 42–75.

(2) CLOUGH, H. W.
1924. A systematically varying period with an average length of 28 months. Mo. Wea. Rev. 52: 421–441.

(3) CLOUGH, H. W.
1921. A statistical comparison of meteorological data with data of random occurrence. Mo. Wea. Rev. 49: 124–132.

(4) WALKER, G. T.
1925. On periodicity. Quar. Jour. Roy. Met. Soc. 51: 337–346.

(5) BESSON, LOUIS.
1920. On the comparison of meteorological data with results of chance Mo. Wea. Rev. 48: 89–94.

(6) FRITZ, H.
1878. Die beziehungen der sonnenflecken zu den magnetischen und meteorologischen erscheinungen der erde. Haarlem, 1878.

THE RATE OF DECAY OF ATMOSPHERIC EDDIES

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INTRODUCTION

The way in which eddies are produced and the rate at which their energy is dissipated in actual fluids is a matter of considerable importance, both from a practical standpoint as a measure of the effect of viscosity on atmospheric motions in its relation to aerodynamical and meteorological problems, and also for theoretical reasons as a means of furnishing a desirable basis for, and a check upon the mathematical investigations regarding the motion of perfect fluids; that is, fluids in which similar motions may occur and which may have all of the other properties of actual fluids, but which we may imagine to be entirely devoid of internal friction, or viscosity.

In the present paper it is attempted to investigate the dynamical nature of individual eddies, their growth and rate of decay, etc., rather than to make a statistical study of the combined behavior and average effect of a large number of them, which has already been so admirably done in the work of a number of other students of this subject.

The theory is more or less restricted to eddy motions taking place at a fixed altitude and with supposedly the least possible exchange of thermal and gravitational energy, and therefore only a slight reference will be found to that part of the problem relating to the motion of eddies which may, over a given time, be increasing, or decreasing with height relative to any fixed levels.

OBSERVATIONS ON THE DISSIPATION OF EDDY MOTION

Selecting certain days when the air was very clear and quiet, some attempts were made to determine the rate of decay of eddies set up and following in the rear of railway trains, motor cars, and other vehicles moving on, or near, the earth's surface.

The methods employed in this investigation were necessarily of such nature as to afford but little opportunity for making any very exact measurements in the process of collecting the required data, since there were no means available for making an accurate quantitative study of the velocities and time intervals involved, as is otherwise the case where the experiments are under the complete control of the observer, and therefore the results obtained in the present work can hardly be considered as being much more than rough approximations made in the absence of any better and more exact facilities for experiment.

The usual procedure in this investigation was to stand as near the track as possible until the train had passed by and then to release bits of paper or other light material, and observe the lapse of time and how far the train traveled before the eddies caused by its motion had become entirely dissipated.

The distance which the train moved during the interval could not be very accurately estimated in most instances, but knowing the usual speed of the particular train passing at that time and by taking note of certain objects along the right of way which were apparently about even with the rear of the train by the time the eddies, as indicated by the motion of the bits of paper, had completely died away; then by measuring this distance it was possible to obtain a rough estimate of how far the train had traveled during that period of time.

It was found that in the case of a fast passenger train moving at a speed of around 25 meters per second (or about 56 miles per hour), the eddies formed by its motion

seemed to be dissipated in about 12 seconds; that is, the air over the tracks had settled into its usual quiet state again after the rear of the train had reached a point about 1,000 feet away.

At 12.5 meters per second the distance traveled was approximately 375 feet and the time required for the air to become quiet again was about 9 seconds, and at one-half the above-mentioned velocity, or about 6.25 meters per second (14 miles per hour), the distance was around 125 feet and the time 6 seconds.

This seems to indicate that the rate of decay is quite rapid at the relatively higher speeds, but the motion of the eddies becomes much more persistent for equal time intervals at lower velocities.

In the curve Figure 1 is shown the relation between the speed of the train and the time rate of decay of the eddies produced by it. The part of the curve indicated by the dotted line is that which it is assumed would be obtained if the speed should be doubled three or four times beyond that at which the actual observations were made.

It is found that the velocity (that is, the apparent velocity within the eddies as determined with reference to the relative speed between the body and the air) falls 50 per cent for equal time intervals from whatever is considered the initial value given them at the particular instant when they are first developed; and the curve becomes asymptotic to the vertical ordinate at something less than 770 miles per hour, which seems to indicate that at velocities exceeding that of sound the eddies themselves cease to acquire any additional velocity as the speed of the body increases beyond this point, and it is quite probable that the disturbance created by the motion of the body changes to one of a fundamentally different nature after reaching this value.

It is of considerable interest to study the motion, or flow pattern, of the air along the side and in the rear of a fast-moving train.

Stepping on to the middle of the track and releasing a handful of small bits of paper immediately after the last car had passed by it was found that these bits of paper at first flew away after the train with almost the same velocity as the train itself. Their motion was practically always slightly downward between the rails, then outward toward each side of the track and then upward, sometimes higher than the car. Their path of motion, in fact, seemed to follow the turns of a long helix, one on each side of the track and revolving in opposite directions. Since the motion near the ground seemed to be always outward and then upward from each side of the track, there must be a corresponding inflow over the top of the train and downward over the middle of the track.

Figure 2 is a two-dimensional diagram of the flow pattern of the eddies produced by a moving train. This may be a rather idealized picture of the circulation, because it is not certainly known whether or not the paths of motion are nearly circular about two imaginary central lines parallel to the direction of the train. The distribution of velocity and the pattern of the streamlines in the actual motion may, of course, vary considerably from one instant to another on account of the variations in air movement, but for the purpose of analysis we can imagine the motion to be steady at any one instant and the paths of motion of the air in each eddy to follow the circular pattern shown in the diagram, and at the same time there is also a motion of translation in the same direction as that of the train, so that the actual path for the fluid elements of each ring is that of a helix.

The movement of the air disturbed by the train could easily be detected at a distance of about 4 meters on either side of the middle of the track when there was no cross current of wind and the extent of this disturbance seemed to be always of the same dimensions no matter whether the speed of the train was 15 or 60 miles per hour.

Almost every portion of fluid in whatever path of motion it may follow always has a certain cause, somewhere, for its taking that particular course, and the most complex motions may have definite laws which can explain their behavior when once we understand them.

The twin helices of air motion following immediately in the rear of most bodies, and especially those of rather abrupt form, are quite well defined and unmistakable. They may be easily observed from the rear window of an automobile when moving at a moderate speed along a dusty road, or they can be distinguished in the whirls of dust and in the exhaust smoke from a car a short distance ahead. The scatter of leaves, bits of paper, etc., from under a passing automobile or street car will give the same indication, and perhaps another more ideal place for observing this systematic type of turbulent motion would be the rear platform of a railway coach, especially from the parlor-observation car at the end of the train.

The most important, and at the same time the most difficult, problem connected with observations on the decay of eddies set up by moving bodies is that of determining the initial tangential velocities within the eddy itself, as the rate of decay was found to depend only on this circulation and was not in any way directly related to the speed of the train or other body from which the eddies were produced, or to the forward speed imparted to the air in the following flow.

In fact, by the time the revolving motion around the helical axis has died out, the forward motion of the whole turbulent wake of fluid will also have been dissipated.

The only available means of determining these velocities was to measure the distance from the point where the bits of paper were released to the point where they were deposited along the right of way by the outward moving portion of the circulation near the ground. Then, since the path followed by these particles with reference to a plane normal to the helical axis formed about one-fourth of the outer circumference of the eddy, and knowing the approximate speed of the train, it was possible to obtain a rough estimate of the tangential velocity of this outer ring of fluid by taking the ratio between this distance and the distance which the train moved during one second of time.

Thus in one series of observations the mean distance from a point in the middle of the track where the bits of paper were released to the point where they were deposited by the outward moving air current was about 61.3 feet, in the case of an express train moving at a speed in the neighborhood of 25 m. p. s. Then, since the radius of the outer part of the eddy was found to be approximately 2 meters, the time taken for the particles to move over one-fourth of their path in describing the circumference of this outer ring was about three-fourths of one second.

Another series of observations made under about the same atmospheric conditions, but in the case of a train moving only at about 41 feet per second, gave a distance slightly in excess of 40.5 feet, and therefore the time taken to move around one-fourth of the circumference was also one second.

An exact formula was worked out for the purpose of making a quantitative analysis of these motions and for the determination of the velocities therein, and this

method together with the results obtained from it will be explained in another section of this paper.

The data given above are only very rough approximations and no claim is made in regard to their being entirely accurate, but since they represent the average values derived from a large number of observations it is hoped that they may be accepted for the present, and perhaps with more precise methods of experiment the exact relations can be determined later.

Shortly after making the first preliminary attempts to measure the tangential velocities within eddies produced by railway trains it was noticed that these velocities were not directly proportional to the relative speed, and in fact they did not seem to bear any definite relation whatever to changes in the relative motion between the body and the air.

The eddy motion in the rear of one train moving at twice the speed of another did not appear to have anyways near the increase in velocity that it should have in proportion to the difference in the relative speed.

This was rather a puzzling situation until it finally became apparent that as the air in the layer next to the surface of the car was dragged along with it in its motion, the velocities in the eddies produced in the rear of the train depended upon the rate at which this marginal layer escaped from the forward drag of the cars, or upon the rate at which the fluid elements were shed backward from the rear terminus of the boundary layer.

In Figure 3 it is attempted to illustrate what actually takes place when an air current passes along a stationary wall which suddenly breaks off at an angle. It is assumed here for convenience that the motion is steady and two dimensional.

The fluid immediately in contact with the wall is at rest relative to it and the transition from the stationary to the moving elements occurs in this marginal layer near the surface. Then the velocity in each succeeding layer outward in a direction normal to the surface becomes greater as this distance increases until it reaches that of the undisturbed flow.

The fluid layers next to the boundary probably contain elements moving with very high vorticity to compensate for the transition from the moving to the stationary air, but the details of this action can be ignored for the present, as what concerns us most now is the relative velocity between the body and the layer in motion immediately outside the boundary. As this layer moves along and reaches an abrupt corner of the body it meets with the marginal layer in contact with the rear surface and whatever velocity may be permitted it by the compensating actions taking place between this layer and the actual surface will allow a corresponding amount of fluid to be released from that portion having what would otherwise be the same velocity as the body itself.

When a body, such as A in the diagram, moves at any velocity relative to the undisturbed flow F, the motion within the two marginal layers B and D are equal, although they are not of the same thickness, and as the fluid is fed backward it requires a replacement of new elements from these two directions which sets up a circulation around C.

The next succeeding layer outside of the one affected by the boundary, although it has a higher velocity relative to that of the body, is less disturbed in its motion, and the other outer layers are still less affected until at a certain distance the velocity becomes that of the total undisturbed flow.

If the motion of the fluid fed back from the boundary layer was the same at all points of the rear edge of the surface, and if from each point the flow should be always parallel to the general direction of the relative motion between the body and the fluid, as implied by the two-dimensional diagram shown herewith, then the eddy motion would consist of a circulation set up around an axis parallel to the terminal edge of the boundary layer; but if other surfaces should be arranged so as to establish a three-dimensional flow it would be very difficult to provide for all points to have equal vorticity, or for all portions of the boundary layer to be of uniform thickness, and for the fluid elements contained in this layer to have everywhere the same direction and velocity, etc., except in such cases as may occur where a symmetrically shaped body like a cylinder was made to move parallel to its axis through the fluid.

In most cases of three-dimensional motion, however, with bodies of other than circular cross section, there is a tendency for more air to be shed backward from one point than from another as, on account of the unequal distribution of pressure, the direction of flow is not always parallel to that of the relative motion, and therefore because of this convergence, or divergence of the air flow to, or from certain points of the marginal layer a circulation is produced around axes parallel to the general direction of motion which originate at the rear surface of the body and extend back over the path traveled since the beginning of its motion.

This is one of the few types of flow which seem to meet all the conditions for stability, but to this statement a reservation must be added to the effect that this obtains only so long as the oppositely directed centers of rotation are not made to approach too near each other.

As far as could be learned from the observations previously described the two centers of oppositely revolving fluid in this case preserved their identities until the motion was completely dissipated.

There may naturally be some doubt as to whether or not the size of an eddy remains constant over all ranges of relative velocity between a solid body and the surrounding fluid.

As already stated a moving train seemed to distrub the air only to a distance of about 4 meters to either side of the middle of the track which it passed over, regardless of whether it was moving fast or slow. It was found to be quite easy to step into or out of the air movement caused by its motion while the train passed, as the boundary of the disturbance was very clearly defined.

The particular point of interest in this connection, however, outside of determining the extent of the disturbance for different speeds, was that if one stood at a certain distance from the track, the faster the train was moving the further the head end of it was past before the air blast could be felt. For a slow moving train the rush of air along side of it was experienced almost at the same time as the engine passed, but in the case of a fast moving express this rush of air could not be felt at a distance of 4 meters from the middle of the track which it passed over until two or three seconds after the front end of the locomotive was past. Of course when one stood nearer the track the disturbance in the air became apparent much sooner than that, but in no case, providing the surrounding air was quiet at the time, did this disturbance seem to extend much beyond 4 meters from the middle of the track.

It should not be understood from this, however, that eddies formed by the relative motion between a body

and the surrounding fluid do not ultimately assume any larger dimensions than those to which they develop near the disturbing object.

It is simply intended to point out here that there is a definite relationship between the size and shape of the body and the size of the eddies which it creates in the fluid at the instant of their maximum development, and this seems to be independent of the relative speed; but this does not mean that there can be no spreading out, or a more or less increase in the size of the eddy under the influence of viscosity after it is once free of the forces by which it was produced.

MATHEMATICAL THEORY

The theory of dissipation of eddies has been investigated mathematically by Taylor (1), (2), Webb (3), and Bateman (4), and also by Richardson (5) and Fujiwhara (6).

Since Taylor was the first to formulate the dynamical principles of this theory and his analysis (1) has formed the basis for most of its subsequent development, a brief résumé of his paper will be given here for the benefit of those who are not already familiar with it, and a few notes will also be added in regard to the more important points in some of the other papers mentioned.

In Taylor's analysis the motion is supposed to be two dimensional. If we let ω be the angular velocity of a ring of fluid of radius r, the tangential velocity $v=\omega r$.

Then if μ is the viscosity and ρ the density, the equation for the motion of any ring is

$$(1)\quad \frac{d}{dr}\left\{2\pi r^2 \mu r \frac{d\omega}{dr}\right\} = 2\pi r^3 \rho \frac{d\omega}{dt}$$

where t = time.

Substituting $v=r\omega$ and $\nu=\frac{\mu}{\rho}$, the equation becomes

$$(2)\quad \frac{d^2v}{dr^2}+\frac{1}{r}\frac{dv}{dr}-\frac{v}{r^2}=\frac{1}{\nu}\frac{dv}{dt}$$

By substituting a new variable θ, in the velocity term, the above equation becomes

$$(3)\quad \frac{d^2\theta}{dr^2}+\frac{1}{r}\frac{d\theta}{dr}=\frac{1}{\nu}\frac{d\theta}{dt}$$

which is identical with that for the conductivity of heat

In this case a solution for θ is known to be

$$\theta=\frac{A}{t}e^{-\frac{r^2}{4\nu t}}$$

Hence a solution of (2) is

$$v=\frac{d\theta}{dr}=-\frac{Ar}{2\nu t^2}e^{-\frac{r^2}{4\nu t}}$$

On putting

$$(4)\quad \zeta=\frac{r}{\sqrt{4\nu t}}$$

it will be found that

$$(5)\quad v=Bt^{-\frac{3}{2}}\zeta e^{-\zeta^2}$$

where B is a constant.

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Considering an eddy of a type in which the velocity is zero at the center and at infinity; this velocity is a maximum where

$$\zeta=\frac{1}{\sqrt{2}}$$

And if the radius R of the eddy be defined as the radius of the ring of maximum velocity, it will be seen from (4) that

$$(6)\quad \zeta=\frac{1}{\sqrt{2}}=\frac{R}{\sqrt{4\nu t}}$$

Hence $$(7)\quad R=\sqrt{2\nu t}$$

Here t evidently represents the time taken by the eddy to attain a radius R, starting from the condition in which ν and ω are infinite at time $t=0$. This may therefore be called the "age" of the eddy.

We may imagine that an eddy of radius a is formed and that it is of standard form given by equation (5). Then its initial "age" t_0, i. e., the time it would have taken to form itself from a nucleus originally concentrated along the axis is given by (7). It is

$$(8)\quad t_0=\frac{a^2}{2\nu}.$$

Taylor has shown that at some later time when the "age" is t, the velocity will have died down to $\frac{1}{n}$th of its initial value where t is given by

$$\frac{1}{n}=\frac{t^{-\frac{3}{2}}}{t_0^{-\frac{3}{2}}}$$

and therefore $$(9)\quad \frac{t}{t_0}=n^{\frac{2}{3}}$$

Hence from (8) and (9) the time taken for an eddy of initial radius a to die down to $\frac{1}{n}$th of its velocity is

$$(10)\quad t-t_0=t_0\left(n^{\frac{2}{3}}-1\right)\frac{a^2}{2\nu}\left(n^{\frac{2}{3}}-1\right)$$

Putting $\nu=.14$ and taking the case of an eddy whose initial diameter is about 0.6 cm. corresponding with a cylinder of the same diameter, then $a=0.3$ cm. and $\frac{a^2}{2\nu}=0.32$ second.

Therefore the time taken for an eddy to die down to half its velocity is found by putting $n=2$, in equation (10). It is 0.18, or about one-fifth second.

In Webb's paper both the development and decay of an eddy, under the combined influence of a line source along the axis and viscosity, is investigated mathematically and a solution is obtained of Taylor's equation (2) to which has been added the term $+\frac{2cv}{r^2}$, where c is a constant and is connected with the radical velocity by the relation $u=\frac{c}{r}$.

Bateman has obtained a generalization of Taylor's equation which gives a solution of the three-dimensional problem of an eddy with a source or sink along the axis, following the type considered by Webb.

Bateman's paper contains some interesting mathematical relations connected with the theory of this type of motion and points out an analogy between the theory of eddies in a viscous fluid and the Quantum theory of radiation.

He has also obtained another exact solution of the equations of motion of a viscous fluid which gives a result comparable to the well-known principle that a horizontally stratified atmosphere is unstable when the lapse rate of temperature is higher than the adiabatic value.

Lamb (7) has given some attention to a problem quite similar to this, in which the fluid motion is supposed to be in circles about an axis, the velocity being a function of the distance r from this axis.

A very good summary as to the general nature of this problem is to be had in a quotation from a part of Taylor's paper in which he explains the dissipation of eddies as probably being due to two main causes; "(a) the action of viscosity between rings of fluid rotating with different angular velocities, and (b) forces due to dynamical causes which tend to reduce the tangential velocity in the eddy. A possible cause of this kind would be the flow inward from the ends of the eddy toward the middle, down the axis of the eddy. This flow would allow the radius of the rotating part to increase and at the same time the velocity would necessarily decrease in order to keep the angular momentum constant.

The action, in fact, would be the opposite of that of a sink; e. g., the waste hole in a bath, where the taking away of fluid from the middle decreases the radii of the rotating rings of fluid and consequently increases their angular velocity.

It is very important that a marked distinction should be made between two different kinds of eddies, or rather between two different stages of their life history. In their first stage, that of growth and development, their motion is produced and maintained by forces external to that of the eddy circulation, such as the dynamical interaction between two currents having different velocities or directions, or between the fluid and a solid body in motion relative to each other; whereas the second stage, or that of decay, the motion is due entirely to the momentum of the fluid mass within the limits of the eddy itself.

In the first stage the field of motion may be built up from one or more nuclear axes, or filaments, and it will continue to be maintained against the retarding action of viscosity so long as the external forces remain operative. This type may be known as a *driven* eddy.

It often happens, however, that these external forces are but momentarily active upon a definite portion of fluid, and following the application of a sudden initial impulse sufficient to start the motion, these forces may as suddenly cease to act, after which the motion is kept up almost entirely by the momentum imparted to the fluid until it is finally dissipated by opposing forces due to the friction between the relatively moving elements of the fluid. This type may be known as a *free* eddy.

Before attempting a quantitative discussion of the results obtained in the present study, it is necessary to make certain fundamental assumptions as to the exact nature of the particular form of fluid motion that is here under consideration.

1. It is assumed that, except within a limited region very near the axis the tangential velocity is inversely proportional to the radius, or in other words, that the product of the circumference of any selected streamline circle and the velocity on this circumference is constant and has the same value for every circle outside of the central nucleus, since the velocity decreases in the same ratio as the circumference increases. The tangential velocity is greatest at the ring forming the boundary between the rotating and nonrotating parts of the eddy, and the velocity of the external field of fluid at an infinite distance from the nucleus is taken to be zero.

In the practically important cases the velocity in the irrotational part reduces to that of the main stream of fluid generating the motion within a certain limited distance of the nucleus.

In view of the foregoing it will be easily understood that the angular momentum of each ring of fluid represented by any streamline denoting the flow around the axis at any given distance from it, has a constant value which is the same for each successive ring between the outer and inner limits of the irrotational field.

2. The retarding force due to the action of viscosity between successive rings also has a constant value at any point within this irrotational field of motion, and is directly proportional to the differences in velocity between each of the different rings. The total retardation within the whole eddy may be considered to have the same value as it would have if it were confined entirely to the circumference of the ring of maximum velocity.

There is then a constant relation between the radius of any ring of fluid outside of the nucleus, the angular momentum, and the amount of retardation due to viscosity, and it is therefore independent of the dimensions of the eddy.

3. The radial velocity is directly proportional to the tangential velocity; and the inflow parallel to, or along the axis, is proportional to the *square* of the tangential velocity.

Note.—In speaking of "rings of fluid" it should be understood that this is merely a convenient expression for describing the flow and that actuelly they must represent such a small radial difference that there can be no relative motion between their inner and outer limits.

It simply makes the analysis easier if we imagine the fluid elements involved in the motion to be separated into rings which decrease in velocity and increase in thickness as their radius increases.

In order to describe more fully the various details as outlined in our first assumption in regard to the distribution of the velocity and angular momentum of a fluid revolving around a central nucleus, it may be stated that we need only to know, aside from the fact that the region outside the nucleus is free from rotation, the location and the diameter of this nucleus and a single number which designates the velocity at a unit distance from it. Instead of this last number, one 2π times as large is usually given, which is termed the "circulation." It is the product of the circumference of any selected streamline circle and the velocity on this circumference. As already mentioned, this product is the same for every circle outside the nucleus, since the velocity decreases in the same ratio as the circumference increases. This "circulation" number therefore defines the magnitude of the nucleus. If the rotation in the nucleus is uniform (like a solid body), then the "circulation" is equal to the product of the rotation times the area of the nucleus, for, if r represents the radius of the nucleus and ω the angular velocity, then the circumferential velocity of the nucleus is $r\omega$, the circumference is $2\pi r$ and the circulation is their product: $2\omega\pi r^2$, which equals the product of the area of the nucleus πr^2 times the rotation 2ω. If the rotation is not uniformly distributed then its mean value must be taken, which multiplied by the area of the nucleus, will then give the circulation about the nucleus.

It is thus seen that it is only necessary to know the location of the rotating parts of the fluid and the amount

of their rotation in order to determine all the rest of the data. It may seem strange to many that anything so small as the nucleus of a vortex can exert a determining influence on all the rest of the current. The explanation lies in the assumption that the flow is free from rotation with the exception of the small area of the nucleus. Perhaps this nucleus is often wrongly regarded as the mechanical cause of the vortex field. As a matter of fact, the irrotational flow is produced by pressure, and where there is considerable shearing stress, regions of rotational motion are generated which are variously distributed by the motion of the main current.

It may therefore be said more truthfully that the whole flow generates and distributes the vortex nuclei. In any case, the size and distribution of the nuclei is very closely connected with the motion of the rest of the fluid, so that we may calculate backward from the distribution of the nuclei to the corresponding irrotational flow.

As the motion dies down the neighboring parts of the fluid are likewise gradually set in rotation and themselves form components of the nucleus. Hence the nuclei gradually spread out. The "circulation" about the nucleus is not changed thereby, because we can always measure it at any desired distance from the nucleus, hence at so great a distance that the influence of the viscosity is not felt.

If, however, the nucleus enlarges without increasing the circulation, then the mean rotation of the fluid in the nucleus must have been distributed over the larger area. The law that the "circulation" remains constant in this extension of the nucleus, holds good only so long as two or more nuclei do not merge into one another.

And further, according to this law, the nucleus can not end therefore at any point whatsoever in the fluid. It must either form a closed ring, or spread out to infinity, or end at the edges of the fluid. (8).

The latter condition is always present in practically every case with which we are concerned, since most eddy motions in the atmosphere always take place in the neighborhood of the boundaries formed by solid bodies, or within a reasonable distance of the earth's surface.

It should be mentioned here that what has just been said in regard to the fundamental laws of vortex motion, and their close approximation to actual conditions in the local eddying, or turbulent motions of the atmosphere, can not be applied to any such large scale motions as the migratory cyclone of the temperate latitudes and possibly only with certain modifications to intense tropical cyclones, because the ordinary cyclonic disturbance is of such vast area compared to its vertical extent and there is such a great difference in the temperatures and water vapor content, etc., of the different air streams which go to form part of its general wind system, that there is only a very slight similarity between it and an ordinary eddy, unless these other more complex relations are fully accounted for.

The mean temperature of the air during the period in which the observations on the rate of decay of eddies were made was about 64.5 F., or 18 C.

Now the density ρ of air at this temperature and at about 41 N. latitude and at an altitude of 225 meters above mean sea level is 0.00120 g/cm., or 1.20 kilograms per cubic meter.

The coefficient of viscosity of air varies in relation to its temperature and, according to information furnished by the United States Bureau of Standards, about as good a formula as any for determining this relation is

$$\mu = 0.00018240 - 0.000,000,493(23 - t^\circ)$$

Since t° in this case = 18.0 C., then $\mu = 0.000179935$, or practically 0.00018; the kinematic viscosity $\nu = \frac{\mu}{\rho}$ is therefore

$$\nu = \frac{0.00018}{0.00120} = .15.$$

Now, if we consider the inside of the eddy near the axis as a region of uniform vorticity defined by the relation v prop. r, where r is the distance of a point from the central axis and v is the tangential velocity at that point at right angles to r, then if at every point outside of this central nucleus the velocity decreases in the same ratio as the circumference increases, this outer region will have no vorticity and the momentum of the fluid contained within a very thin ring, say, that defining the boundary between the rotational and irrotational portions of the eddy, will be equal to $2\pi r v \rho dr$, where dr is the thickness of the ring; and, further, since the product of the velocity and the circumference is constant for each ring of fluid outside the nucleus (within the limits of the irrotational field of motion), therefore the total angular momentum of the fluid contained in the whole cross-sectional area between the inner and outer limits of the irrotational field will be

$$M = \int_0^\infty 2\pi r^2 v \rho dr$$

Since by our second assumption the retarding action due to friction between the different rings is also constant and has the same value at every point within this region, the time taken for an eddy of this type to die away will therefore depend on the excess of energy due to the momentum of the fluid within the boundaries over the retarding action caused by the viscous drag, or shearing stresses, developed between the different rings. Hence, as a comparative measure

$$(1) \quad \tau = \int_0^\infty \frac{2\pi r^2 v \rho dr}{2\pi r^2 \mu dr}$$

As we may cancel those parts of the expression which define the size of the eddy, we have simply

$$(2) \quad \tau = \frac{v\rho}{\mu}$$

Thus the time rate of dissipation depends only on the density and viscosity of the fluid and it is directly proportional to the maximum tangential velocity of the eddy relative to the surrounding medium.

In determining the tangential velocity of the fluid within the irrotational part of the eddy it is, of course, necessary to determine it with reference to some point at a certain radial distance from the center, and it is in this part of the problem that we are concerned with the dimensions of the flow.

It proved to be rather difficult to find a method of making exact calculations of the tangential velocity of the fluid following the helical path of motion described, but after considerable study a fairly satisfactory formula was worked out, which will probably be made clearer by reference to the diagram Figure 4.

In this case supposing dx to be the distance which the train moved in one second, and ds the distance to which the bits of paper were carried during the same interval while they moved to a point approximately one-fourth the way round the circumference of a circle of radius

$r=2$ meters from the point where they were released, then the tangential velocity around the helical axis was found to be given by an expression of the form

$$(3)\ v=\frac{d\theta}{dt}=\frac{d\theta}{ds}(dx-ds)+\frac{d\theta}{1}.$$

Where θ is the distance in meters around that part of the circular path over which the particles moved in unit time and it is related to v by the relationship $\frac{d\theta}{dr}=v$.

For a train moving at the rate of about 28 miles per hour the tangential velocity was found to be something like 3.15 meters per second, so that

$$\frac{v\rho}{\nu}=25.2.$$

Now if the density and other conditions of the fluid should remain the same, but the velocity be varied by a given amount, it is necessary to multiply $\frac{v\rho}{\nu}$ by some constant in order to determine the rate of decay corresponding to the new velocity.

At an initial tangential velocity of around 3.15 meters per second the time required for it to have become entirely dissipated was found to be about 9 seconds.

The coefficient connecting the rate in this case with that of any other velocity, under similar conditions, is therefore

$$(4)\ c\tau=\frac{25.2}{9}=.3572.$$

Hence the rate of decay for any other eddy in a fluid having the same density and other physical characteristics as that in which these observations were made, but differing in velocity and dimensions only, will be given by

$$(5)\ \tau=\frac{v\rho}{\nu}\ (.3572).$$

It is not known what may be the value of $c\tau$ in air of a different density, etc., from that in which the above values were obtained. It must necessarily increase with altitude, but its exact relation to density is as yet undetermined.

If this value increases in the same ratio as the density decreases, then the time rate of decay for an eddy starting with a given initial velocity would be the same at all altitudes, providing, of course, the motion of each of its component elements takes place under normal conditions as to temperature and density, etc., pertaining to that altitude at which the motion may occur.

In other words, this value would change if the eddy itself should be moving upward or downward, or if within the field affected by its motion there should be a transport of air from one level to another.

It is very likely that $c\tau$ increases more rapidly than the proportional decrease in density, and at any rate it is probably many times greater at a height of two or three thousand meters than what it is near sea level.

It is also admitted that so far this study has not furnished any information as to what proportion of the dissipation of eddy energy may be due to dynamical causes and what part to viscosity, because, as Taylor has already remarked, the exact distribution of the velocity is not known.

But without this information it may be permissible to assume, however, that the axial and radial motions in eddies of this type are related to the tangential velocities in such manner that the part of the decay caused by the dynamical effect is a function of the decrease in velocity of the fluid revolving around the axis, and if the rate of this decrease is known it might be taken as a measure of the effect due to both causes.

It seems there have been no very recent studies made with a view of computing the actual velocities which occur within eddies of the type in which the dynamical effect would be fully developed. The only information available to me at the present time is that contained in a series of papers by Prof. F. H. Bigelow on "Studies on the vortices in the atmosphere of the earth." **(9)**.

I believe the results of his analysis of the motion of air and its component velocities within tornadoes and waterspouts are entirely dependable and sufficient in representing actual conditions for the purpose of determining the relationship between these different velocities, and from a study of Table 35, contained in his analysis of the St. Louis tornado of May, 1896, it was found, at least for that part of the data which I have studied, that the radial and tangential velocities are connected by the relation $\frac{v}{u}=Cu$, a constant, and the motion parallel to, or along the axis, is connected by the relationship $\frac{v^2}{w}=Cw$, constant, which is according to our third assumption that the radial velocity is directly proportional to the tangential, while the axial velocity is proportional to the *square* of the tangential velocity.

The experimental data on which Taylor and Webb have based their discussion in comparing the mathematical theory with the results obtained from some actual measurements of the rate of decay of eddies in a wind tunnel, are contained in a paper by Relf and Lavender **(1a)** on an investigation of the effect of upwind disturbances upon the forces measured on models placed in the channel.

Their experiments were made with a screen of vertical cords of ¼ inch (0.6 cm.) diameter spaced near each other across the tunnel, for the purpose of learning just what effect the eddies set up by such a screen might have upon the forces measured on models at various distances behind it.

They found that the time taken for an eddy of a given initial size to die down to a given fraction of its original intensity is constant, and the distance in which a given decrease in intensity results should therefore be proportional to the wind speed.

My own observations have clearly substantiated the first part of this general result, but they have failed to give quite the same indication in regard to their assertion that a given decrease in intensity should be in proportion to a definite fraction of the wind speed, since, as already mentioned, no direct linear relation could be found between the two in the case of the experiments described in an earlier part of this paper.

The results obtained from these observations have appeared to indicate that the tangential velocity of the eddy motion does not increase proportionally as the velocity of the mean motion increases. It is relatively higher at the lower wind speeds, so that we might say, for instance, that the tangential velocity increases more rapidly in proportion to an increase of from 10 to 15 meters per second in the mean motion than it does to an increase of from 20 to 25 meters per second.

In one case where the mean relative velocity was a little over 40 feet per second, the tangential velocity was 3.15 m.p.s., while on the other hand, when the mean velocity was around 25 m.p.s., the tangential velocity was found to be only 33.3 per cent greater, or about 4.2 meters per second.

In Relf and Lavender's experiments, for a wind speed of 6.1 m. p. s., the required distance of the screen from the model to reduce the effect to half value was 22 inches. At 12.2 m. p. s. the distance in which the effect was halved was 38 inches, and at 18.3 m. p. s. it was 48 inches.

The screen ceased to have any effect on the model when the distance between them was increased to about 7 feet, so that at this distance the result was practically the same as that for a clear channel.

In other words, this would mean that if we reversed the process and assumed the screen to move through still air at a speed of 12.2 m. p. s. (40 feet per second) the eddies produced at a given point will have become entirely dissipated by the time it has moved about 7 feet.

$$\text{Now } \frac{v}{l}=\frac{40}{7}=5.7 \text{ and therefore } \frac{1}{v/l}=0.1754$$

or practically 0.18 second.

Calling this T_2 and let $T_1=9$ seconds (the time required for an eddy of 2 meters radius to die down from an initial tangential velocity of $v_1=3.15$ meters per second at the same wind speed of 40 feet per second), then the tangential velocity v_2 of an eddy of 0.6 cm. radius is

$$(6)\quad v_2=\frac{v_1}{T_1/T_2}=0.063 \text{ meters per second,}$$

which is about one-half of 1 per cent of the wind speed.

Hence

$$\frac{0.063\times 1.20}{0.15}\times 0.3572=0.18 \text{ second.}$$

No doubt the tornado is the most conspicuous and well defined of all forms of eddy motion in the atmosphere, and it is of interest to give some thought to the question of how long one of these violent storms would continue to exist as a free eddy if the source of energy by which it is originated and maintained would suddenly cease to operate.

The maximum tangential velocity of the air near the center of a fully developed tornado has been variously estimated at around 200 to 225 meters per second.

Taking the maximum velocity as 200 m. p. s., the time required for it to become entirely dissipated is found from (5) to be equal to

$$\tau=\frac{200\times 1.20}{0.15}\times 0.3572=571.52 \text{ seconds,}$$

or about 9.5 minutes.

This is approximately what we might expect from actual observation, considering the suddenness with which these storms develop, and the equal suddenness with which they die away and disappear when conditions are no longer favorable for their maintenance.

We may therefore be justified in the conclusion that the source of energy of the tornado [1] is not by any means localized within the area of the disturbance itself, but that it probably has its origin at an altitude of at least one or two thousand meters, and that it is due to some large-scale process of a sudden equalization of the potential differences between oppositely directed air streams of widely different temperatures within that sector of the general low-pressure system where tornadoes are usually known to occur, especially within the southeast or southwest quadrant of a rather intense LOW where a deep current of cold air banked in the rear is being suddenly released and allowed to run under or over the warm current at a comparatively sharp angle so as to set up a very strong mechanical convection and to bring the two oppositely directed air streams into close contact while having a great difference in velocity, temperature, and humidity, etc.

[1] Cf. The Tornado, by W. J. Humphreys, 54: 501-503. Ed.

ON THE PRODUCTION OF TURBULENCE IN THE ATMOSPHERE

In an earlier part of this paper it was explained how eddies are produced by the relative motion between a body and a fluid as the fluid is fed backward and released from the rear terminal of the boundary layer.

The conception of a boundary layer forming the region of transition between a solid body and the surrounding air is of the utmost importance, not only from an aerodynamical standpoint but also in its relation to certain meteorological problems as well.

It is not at all necessary that the fluid movement should be brought to some sort of an abrupt corner in order that eddies may originate from within the boundary layer, as it is entirely possible for eddy motion to be set up after a fluid is made to move for a certain time over a relatively smooth flat surface, and in fact eddies are continually being formed in this way as the wind blows over an open, level field.

In most cases, however, eddies very near the earth's surface are formed by various obstructions to the wind movement, such as buildings, trees, fences, etc., and by variations in surface topography; but these eddies are sensibly stationary, so that in a steady wind any light material, such as dust, snow, or chaff, etc., which may be carried along in the air movement is seen to always follow through the same trajectory, or path of motion, in passing any particular one of these obstructions.

It is quite convincing of this to notice how snow is carried up into wavy drifts over an open field by the action of the wind along the surface, especially when there is already several inches of snow on the ground, and this is scoured by a brisk wind while the temperature is falling, so that the snow is packed considerably as it drifts.

The same thing will also be noticed in the case of snow drifts formed around any stationary object which happens to be in the path of the wind.

It is this process of eddy formation near any relatively stationary boundary of the fluid which is supposed to be the active agency by which momentum is transferred from the fluid to the solid surface, or from one fluid layer to another, where there is a difference in velocity between them.

The intensity of the eddy "circulation" will be proportional to the rate of increase of velocity in a direction normal to the boundary surface.

It would be a matter of considerable interest to know just what relation may exist between the scale of the mean motion—that is, the height or thickness of the fluid strata within which eddies are being produced—and the velocity, or rather the difference in the mean velocity of flow of these separate layers, and the size and intensity of the eddies themselves.

This represents rather a difficult problem because there is so little experimental data available which might be taken even as a partial basis for determining this relation.

In Figure 5 is shown the velocity gradients for different rates of relative motion between two layers of height, h_1 and h_2, moving in opposite directions.

The viscous drag between the two layers brings the relative velocity to zero at some point midway between them, which is here taken to be the boundary of separation of the two currents.

Besides their difference in velocity and direction they are also likely to be of different temperatures and water vapor content.

It frequently happens that where two oppositely moving currents are thus brought into close proximity to each other the velocity gradients reach a certain critical value for those particular layers of fluid, and the stresses developed within them reach the point where stability is no longer possible for laminary flow, and possibly through some local variation in pressure a rotation of a small portion of the fluid will be suddently set up near the boundary between them, which quickly develops into an eddy circulation with an irrotational field around the nuclear axis in accordance with the requirements for the conservation of angular momentum about this central axis.

There is very little possibility indeed of two such relatively moving currents ever being exactly equal to each other and opposite in direction, and even then it would hardly be dynamically possible for the center of rotation to remain fixed in space.

What usually occurs in practically every instance where eddies are formed at the boundary of separation between two currents is for the eddies to be carried along in one or the other, depending upon which is the stronger of the two streams or fluid, so that their tangential velocities about the axis of each individual eddy is combined with a sort of rolling motion along a line somewhere near the boundary.

Some general idea as to the pattern of the streamlines about the moving axis is illustrated here in the diagram, Figure 6.

The actual fluid motion takes place through a process somewhat analogous to the principle of caterpillar traction, where the rolling wheel lays down its own track as it moves along.

In the same way, the fluid flowing round on the forward moving side of the eddy loses much of its velocity of translation as it turns around to the reverse side of the center, as here it is coming into contact with the relatively stationary fluid forming the neighboring portion of the other layer, and in fact a considerable part of one strata may be deposited and mixed with the other in this way as the fluid from more distant regions (higher or lower as the case may be) is drawn in toward the center as it moves along near the boundary.

The temperature and water vapor content of the air thus drawn in would probably vary from time to time, and as would also the amount of condensation taking place, so that we might in this way account for the various forms of clouds observed at different levels where one layer of air may be running over or under another with sufficient relative velocity to cause the formation of eddies.

Now as to the possible relation between the scale of the mean motion and the size and intensity of the eddies produced by it, we may reasonably suppose that the principle which governs this relation in regard to the eddies produced by relatively moving currents in the free atmosphere, is the same as that already mentioned for those formed in the turbulent wake following the relative motion of solid bodies through a fluid otherwise at rest.

Returning to Figure 6, where h_1 and h_2 is the height or thickness of two relatively moving fluid strata within which the eddy motion takes place, u_1 and u_2 are the maximum velocities along the two sides in the directions of x_1 and x_2, respectively; S is the surface of separation between them, where the velocity is supposed to be zero; v is the tangential velocity of the eddy, and V is its velocity of translation along the line connecting the points q_1 and q_2.

It is quite evident that the radius r and the tangential velocity of the eddy must therefore be some function of the height h_1 h_2 and the mean velocity u_1 u_2, and perhaps also the translational velocity V.

If h_1 h_2 are decreased by a certain amount, the radius decreases, and at the same time v would necessarily have to increase if the mean relative velocity between the two streams remained constant; but if this velocity of the mean motion increased without any change in h_1 or h_2, then the radius of the eddy would remain the same and the tangential velocity would not increase by a proportional amount on account of the increase in V. The tangential velocity and also, consequently, the angular momentum measured from the forward moving side of the eddy at any point along a line normal to the direction of q_2 would be equal to $u - V$.

This also applies particularly to the case where one of the fluid layers involved in the relative motion happens to be the comparatively stationary boundary layer immediately in contact with the earth's surface. It is in this region that we find the greatest increase in velocity compared to the least difference in height above the surface, and therefore the eddies are of smaller radius and of greater intensity here than anywhere else.

The combined effect of the rolling motion and the transverse velocity around the moving axes is to modify, or reduce to a minimum, the velocity gradients set up between the stationary boundary layer and the maximum velocity attained by the wind at a given height above the surface.

On account of the fact that this rolling movement of the eddies introduces a more complex relation between the velocity of mean motion and the transverse velocities, referred to these moving axes, it may be that a given increase or decrease in the mean velocity of flow or a certain change in the rate of increase of wind velocity with height does not always result in a proportional difference in the amount of momentum being transferred from one atmospheric layer to another. This is a phase of the problem which will require considerably more study and investigation from an observational standpoint before it can be expected to give entirely consistent and satisfactory results from its analytical treatment.

But while the general problem of turbulent motion in the atmosphere is still far from being thoroughly understood, and there is at present but little hope of its complete solution at any time within the near future, the quantitative investigation of the way in which the wind varies with height and the average rate at which momentum is transferred from one atmospheric layer to another (whatever may be the actual mechanism of these processes) has already reached the point where it has yielded some extremely valuable results. It has been made the subject of a number of very important contributions by Taylor (10), Hesselberg and Sverdrup (11), Åkerblom (12), Whipple (13), Brunt (14), and others.

In the case of turbulent motion at the surface, it has been found that the relation of wind velocity to height follows approximately a logarithmic law, and when there is no change of gradient, or of eddy viscosity with height, the logarithmic relation can be represented by the addition of a vector to the line representing the gradient wind, where the direction is along or tangential to the isobar, such that this added vector represents the actual wind,

both in magnitude and direction, and its point sweeps around an equiangular spiral of 45°, making equal steps of rotation for equal steps of descent from the undisturbed wind to the surface.

A very clear explanation of the law of variation of wind with height has been given in a recent paper by Humphreys (15).

The frictional force R, acting upon unit vloume of the atmosphere, may be measured by the amount of horizontal momentum lost per unit of time. According to Taylor, the components of R along the axes of x and y, are

$$K\rho\frac{d^2u}{dz^2} \text{ and } K\rho\frac{d^2v}{dz^2}, \text{ respectively,}$$

R being a function of the height z.

If we let F be the frictional force per unit surface acting at any place, then it may be shown that

$$R=-\frac{dF}{dz}=K\rho\frac{d^2V}{dz^2}$$

where V is the wind velocity.

Taylor denotes $\frac{1}{2}\, u\rho h$, which he calls the eddy viscosity, by the letter μ, so that the rate of transfer of momentum downward may be written $\mu\frac{\delta V}{\delta z}$.

It follows from this that the rate of transfer downward is

$$\sqrt{2}\mu BR=K\rho V^2.$$

If the thickness of the layer is dz, then the difference between the net flow of momentum into the layer from above and the flow out of it from below is

$$\sqrt{2}\mu B\frac{\delta R}{\delta z}dz.$$

Thus the additional momentum gained in unit time by unit volume of air on account of the eddies is $2B^2\mu R$. Where B is a constant and is independent of Z.

There are two assumptions in connection with this theory which it seems are still to be regarded as lacking in definite proof as to their validity. One of these involves the question as to whether K can always be taken as constant throughout the height considered, and the other is whether B also is constant with height.

Some discrepancy has been found between the observed and theoretical values for the angle between the frictional force R and the reversed wind direction, and apparently this can not be explained on the assumption that B and K are constant with height.

It is possible, too, that the results obtained in a given case may be affected in some way by convectional activity, or by some other factor which has not yet been thoroughly investigated.

There remains to be mentioned one other important relation, derived from the study of the rate of decay of eddies, which may be of some interest in connection with this problem of the transference of momentum between different fluid layers in the atmosphere.

Suppose we let v represent the difference in the mean velocity u_1 and u_2 of two layers at heights z_1 and z_2, respectively, and where this difference in height dz is not too great, we may let ρ be the average density of the air within or between these two layers.

Now for a given initial velocity, and in the absence of any forces except that due to the momentum at the instant $t=t_0$, the time required for the motion to die away is, according to (5),

$$\tau=\frac{\rho v}{v}\times .3572$$

and from this it is found that the rate at which momentum is transferred from one layer to another is

$$(7)\quad Cm=\frac{\rho v/v}{\tau}=2.8$$

So that where the motion is dying down the amount of momentum transferred in unit time is constant and equal to $Cm=2.8\times10^5$ in c. g. s. units, and therefore under steady motion it would require an acceleration equal to the above amount in order to balance the loss due to eddy viscosity.

It will be noticed that Cm is in this case on an average about 3.5 times as large as the mean value for K as determined in the work of Taylor and Åkerblom, and also since its value depends on that of $C\tau$, it is probably not constant with height, but I have not yet had an opportunity to attempt to check or compare this with observational data.

CONCLUSION

As explained at the beginning of this paper, with the limited facilities available it was impossible to attain a sufficient degree of accuracy in the collection of these data for the results to approach what might be considered a final form of exactness. They were presented here only as a first approximation to the solution of the problem, and the discussion which followed was intended to give some idea as to the important bearing which this special subject has in connection with a number of other major problems more or less related to it.

It still remains, however, for much more experimental and observational work to be done, under conditions where it will be possible to make precise measurements of the rate of decay of eddies of various dimensions and at a number of different velocities of mean wind movement.

It is suggested that wind-tunnel tests be made with a delicate Pitot tube, or a hot-wire anemometer, to determine the rate at which the fluid is released from the boundary layer at the rear contour of bodies of various shapes and sizes, and for different velocities of flow; and then the distance to which the effect of a given disturbance, or one of known intensity, is carried, and the time required for it to die away for any given velocity of flow.

A series of tests of this character in a variable-density wind channel should also furnish some valuable information on the variation of $C\tau$ with altitude.

LITERATURE CITED

(1) TAYLOR, G. I.
"On the Dissipation of Eddies." Reports and Memoranda, No. 598, British Aeronautical Research Committee. 1918.

(1a) R. & M. No. 597.

(2) TAYLOR, G. I.
"On the Decay of Vortices in a Viscous Fluid." Philosophical Magazine, vol. 46, p. 671. 1923.

(3) WEBB, H. A.
"The Decay of Eddies." Rep. and Mem. No. 609, British Aeronautical Research Committee. 1919.

(4) BATEMAN, H.
"The Decay of a Simple Eddy." Report No. 144, National Advisory Committee for Aeronautics. 1922.

(5) RICHARDSON, L. F.
"The Supply of Energy to and from Atmospheric Eddies." Proc. Royal Society, A 97, pp. 354–373. 1920.

(6) FUJIWHARA, S.
"On the Growth and Decay of Vortical Systems." 1923. Quarterly Jour. Roy. Met'l. Soc., vol. 49, pp. 75–104.

(7) LAMB, H.
"Hydrodynamics." 5th ed., ch. 11, art. 334, p. 558. 1925.

(8) BETZ, A.
"Vortices and Related Principles of Hydrodynamics." Translated from Zeitschrift für Flugtechnik und Motorluftschiffahrt, by National Advisory Committee for Aeronautics, Technical Notes No. 68. 1921.

(9) BIGELOW, F. H.
"Studies on the Vortices in the Atmosphere of the Earth." Monthly Weather Review, vol. 36, pp. 245–246. August. 1908.

(10) TAYLOR, G. I.
"Eddy Motion in the Atmosphere." Phil. Trans. Roy. Soc. A 215, 1915, p. 1.
Also "Phenomena Connected With Turbulence in the Lower Atmosphere." Proc. Roy. Soc. A 94, p. 137. 1918.

(11) HESSELBERG and SVERDRUP.
"Die Windänderung mit der Höhe vom Erdboden bis etwa 3000 m. Höhe." Beitr. Physik Atmosph., 7, p. 156. 1916.

(12) ÅKERBLOM, F.
"Recherches sur les courants les plus bas de l'Atmosphère au-dessus de Paris. Upsala, Soc. Scient. Acta, 2 (Ser. 4), 1908, No. 2.

(13) WHIPPLE, F. J. W.
"The Laws of Approach to the Geostrophic Wind." Quarterly Jour. Roy. Met'l. Soc., vol. 46, No. 193, January, 1920, pp. 39–53.

(14) BRUNT, D.
"Internal Friction in the Atmosphere." Quarterly Jour. Roy. Met'l. Soc., vol. 46, No. 194, April, 1920, pp. 175–185.

(15) HUMPHREYS, W. J.
"The Way of the Wind." Jour. Franklin Institute, September, 1925, pp. 279–304.

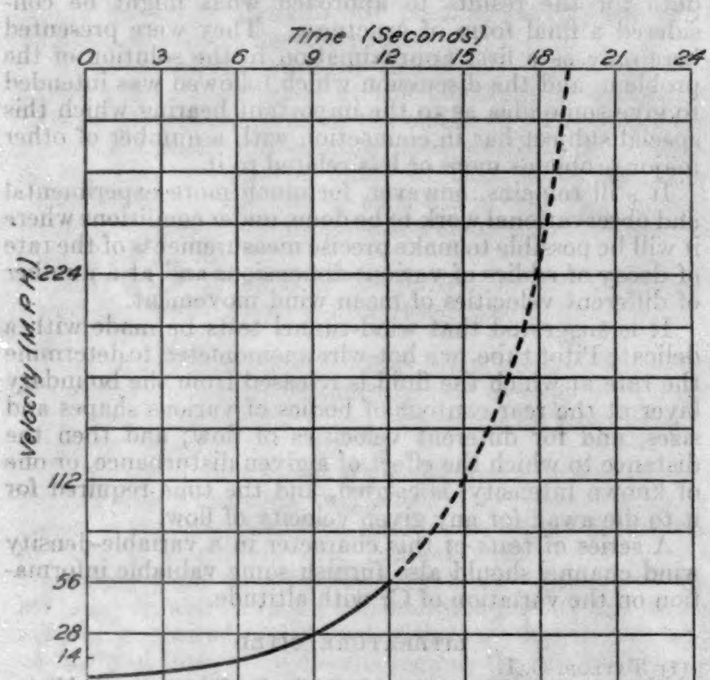

FIG. 1.—Curve showing relation between the speed of the train and the time rate of decay of the eddies produced by it

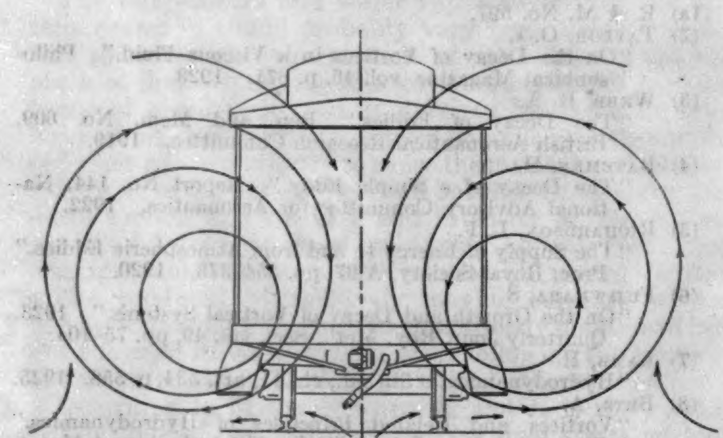

FIG. 2.—Two-dimensional diagram of the flow pattern of the eddies produced by a moving train

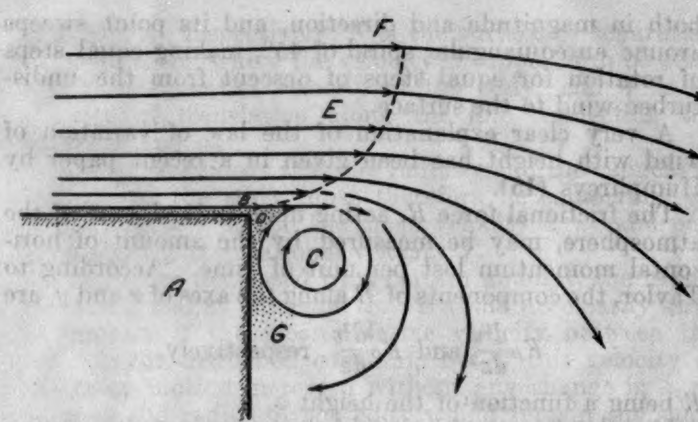

FIG. 3.—Deflection of air current which passes along a stationary wall which suddenly breaks off at an angle. It is assumed that the motion is steady and two-dimensional

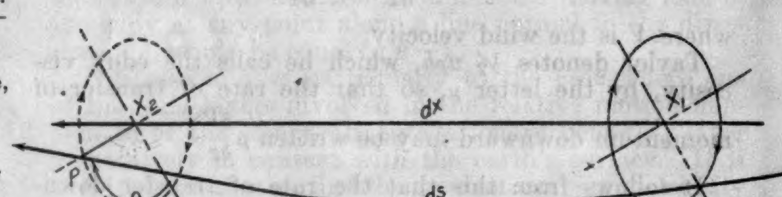

FIG. 4.—Tangential velocity of the fluid following the helical path of motion mentioned on page 269 of this article

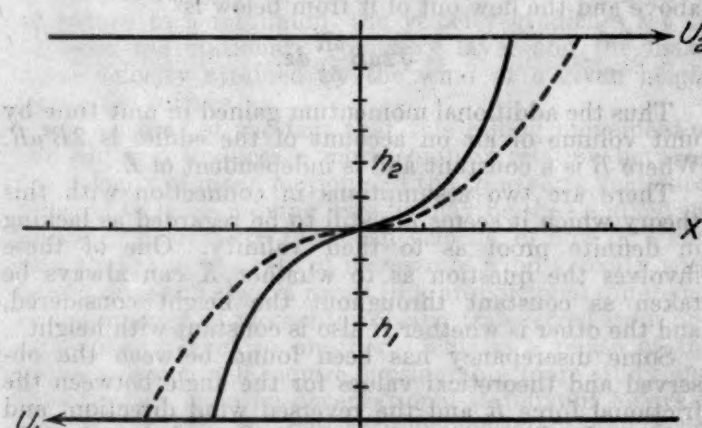

FIG. 5.—Velocity gradients for different rates of relative motion between two layers of height, h_1 and h_2, moving in opposite directions

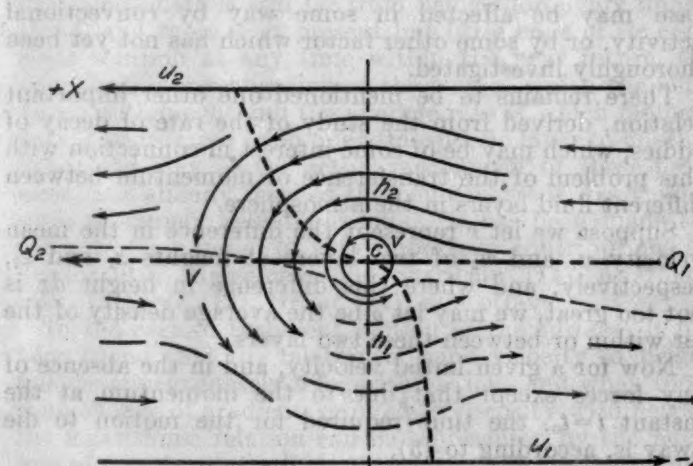

FIG. 6.—Pattern of streamlines about the moving axis

DENSE FOGS AT LINCOLN, NEBR.

By HARRY G. CARTER, Meteorologist

Air traffic is one of the subjects uppermost in the mind of the public to-day, and nearly every city of any size is establishing or already maintaining a suitable landing field. There is, however, one menace to aviation that man has not been able to eliminate, and that is fog. An aviator, by keeing his bearings, may fly his plane safely through or over fog layers; but when landing or taking off, fog is one of the most dangerous handicaps he has to contend with.

With the purpose of learning something of the frequency and duration of fogs at Lincoln a study was made of all dense fogs occurring during the 20 years 1908 to 1927, inclusive, and the data obtained have been tabulated and charted for ready reference. Averages for 20 years should give fairly accurate indications as to what to expect in the future.

Fog is classified by the United States Weathern Bureau as light or dense. A light fog is one that does not obscure objects at a distance of 1,000 feet, and in its most common form, as observed at Lincoln, resembles light haze. A dense fog is one that obscures objects at a distance of 1,000 feet (about two and one-half ordinary city blocks) or less. No degree of density is considered in recording dense fog. Some are so dense they obscure objects at a distance of 25 feet, while others scarcely obscure objects at a distance of 1,000 feet, and the exact time of changing from dense to light or light to dense is rather difficult to determine.

Since light fogs have no important bearing on aviation, except to slightly decrease visibility, the study was confined to dense fogs, and in the discussion which follows when the word "fog" is used the reader will understand that dense fog is meant.

Dense fogs were recorded at Lincoln on 116 days during the 20 years. This is an average of slightly less than six days with dense fogs each year. With the exception of one day in January and two days in February, never more than one dense fog occurred on each day with fog, making a total of 119 dense fogs recorded.

During the 20 years dense fog actually prevailed a total of 354 hours and 33 minutes. This averages approximately about one hour of dense fog every three weeks. Fogs, however, are not evenly distributed throughout the year, a total of 92 hours of dense fog occurring during the 20 Februarys and none being recorded in May. January ranks second, with a total of 80.8 hours, and November third, with 39.7 hours. There were nearly as many hours of dense fog during the months of January and February as during all the other months.

TABLE 1.—*Dense fogs at Lincoln, Nebr., during the 20 years 1908 to 1927*

	January	February	March	April	May	June	July	August	September	October	November	December	Annual
Number of days with dense fog	17	23	10	3	0	5	5	4	17	6	16	10	116
Number of dense fogs	18	25	10	3	0	5	5	4	17	6	16	10	119
Number forming before noon	16	19	10	3	0	5	5	4	17	6	13	10	108
Number forming after noon	2	6	0	0	0	0	0	0	0	0	3	0	11
Total number of hours of dense fog	80.8	92.0	30.8	9.2	0.0	10.4	13.0	9.0	35.7	14.4	39.7	19.5	354.5

Table 1 gives the number of days with dense fog, the number of dense fogs recorded, the number forming before noon, the number forming after noon, and the total number of hours of dense fogs for each of the 12 months and the total for the 20 years. Figure 1 shows the total number of hours of dense fog each month for the period.

There was a marked increase in the number of hours with dense fog from December to February, then a decrease from February to May. The decrease from September to October, the increase from October to November, and the decrease from November to December were quite noticeable. Fewer hours of dense fog were recorded during late spring and late summer than during any other part of the year, 9.2 hours being recorded during the 20 Aprils and 9 hours during the 20 Augusts. At no time during the 20 years did dense fog occur in May.

There was an average of approximately 1 hour of dense fog every week during January and February, 1 hour every 2 weeks during September and November, 1 hour every 3 weeks during March, 1 hour every 4 weeks during December, 1 hour every 6 weeks during October, 1 hour every 7 weeks during July, 1 hour every 8 weeks during June, 1 hour every 9 weeks during April, and 1 hour every 10 weeks during August.

Table 2 gives the total number of dense fogs forming at different times during the day for each month and for the 20 years.

TABLE 2.—*Number of dense fogs which formed at the different hours during the 20 years 1908 to 1927 at Lincoln, Nebr.*

	January	February	March	April	May	June	July	August	September	October	November	December	Annual
Number of fogs—													
Before 6 a. m.	7	8	6	2	0	5	2	2	11	4	6	1	54
Between 6 a. m. and 7 a. m.	4	5	4	1	0	0	3	1	4	2	1	3	28
Between 7 a. m. and 8. a. m.	4	2	0	0	0	0	0	1	2	0	5	4	18
Between 8 a. m. and 9 a. m.	1	3	0	0	0	0	0	0	0	0	1	2	7
Between 9 a. m. and 10 a. m.	0	0	0	0	0	0	0	0	0	0	0	0	0
Between 10 a. m. and 11 a. m.	0	0	0	0	0	0	0	0	0	0	0	0	0
Between 11 a. m. and noon	0	1	0	0	0	0	0	0	0	0	0	0	1
After noon	2	6	0	0	0	0	0	0	0	0	3	0	11

Dense fogs formed most frequently during the early morning hours, 82 dense fogs, or 69 per cent of the total number during the 20 years, forming between 5 a. m. and 7 a. m. Between 7 a. m. and noon, 26, or 22 per cent, formed. No dense fog formed between 9 a. m. and noon.

Eleven formed between noon and midnight, and these were recorded during January, February, and November. In no instance from March to October, inclusive, did dense fog form after 8 a. m. Of the 11 that formed during afternoon or evening 7 dissipated before midnight and 4 continued until after 6 a. m. Of these four one continued until 1 p. m. the next day, lasting 13 hours. The longest period of continuous dense fog was 16 hours and 15 minutes; this was on January 20 and 21, 1919, when a dense fog formed at 5:30 p. m. the 20th and continued until 9:45 a. m. the 21st.

Table 3 gives the number of dense fogs that dissipated during different hours of the day, for each month and for the 20 years.

TABLE 3.—*Number of dense fogs which dissipated during the different hours, for the 20 years 1908 to 1927, at Lincoln, Nebr.*

	January	February	March	April	May	June	July	August	September	October	November	December	Annual
Number of fogs dissipating:													
Before 6 a. m.	0	0	3	0	0	2	0	0	0	0	1	0	6
By 7 a. m.	2	6	3	0	0	4	1	1	3	1	4	0	25
By 8 a. m.	5	7	6	2	0	5	3	2	10	4	8	1	53
By 9 a. m.	12	17	8	2	0	5	4	4	16	6	14	7	95
By 10 a. m.	14	17	10	3	0	5	5	4	17	6	15	10	106
By 11 a. m.	16	17	10	3	0	5	5	4	17	6	16	10	109
By noon	16	17	10	3	0	5	5	4	17	6	16	10	109

Dense fogs lifted most frequently between 7 a. m. and 10 a. m., 100 out of the 119, or 84 per cent, lifting between these hours. By 9 a. m. 95 fogs, or 80 per cent, had lifted, and by 10 a. m., 106, or 89 per cent.

TABLE 4.—*Average duration of dense fogs at Lincoln, Nebr., for the 20 years 1908 to 1927*

Stations	January	February	March	April	May	June	July	August	September	October	November	December	Annual
Average duration:	h. m.	h. m.	h. m.	h. m.	h. m.	h. m.	h. m.	h. m.	h. m.	h. m.	h. m.	h. m.	h. m.
All fogs	4 29	3 41	3 05	3 05	----	2 05	2 36	2 15	2 06	2 24	2 29	1 57	2 59
Those forming before noon	3 32	2 48	3 05	3 05	----	2 05	2 36	2 15	2 06	2 24	2 37	1 57	2 39
Those forming after noon	12 08	5 28	----	----	----	----	----	----	----	----	1 55	----	6 15

Table 4 gives the average duration of all dense fogs, and the average duration of those forming before noon and of those forming after noon, for each month and for the 20 years. Table 5 gives the number of dense fogs lasting less than one hour, those lasting from one hour to two hours, from two to three hours, three to four hours, four to five hours, five to six hours, and those lasting more than six hours, for each month and for the 20 years.

TABLE 5.—*Number of dense fogs which lasted less than one hour, one, two, three, four, five, and six hours, and more than six hours at Lincoln, Nebr., during the 20 years 1908 to 1927*

Stations	January	February	March	April	May	June	July	August	September	October	November	December	Annual
Number of fogs lasting—													
Less than 1 hour	2	1	1	1	0	0	2	1	3	0	2	2	15
1 to 2 hours	4	6	3	0	0	3	1	2	7	3	8	4	41
2 to 3 hours	4	8	2	0	0	2	0	0	2	2	3	2	25
3 to 4 hours	3	5	1	1	0	0	0	0	4	1	1	2	18
4 to 5 hours	0	1	2	1	0	1	0	1	0	0	0	0	6
5 to 6 hours	0	2	0	0	0	0	1	1	0	0	1	0	5
More than 6 hours	5	2	1	0	0	0	0	0	0	0	1	0	9

The average duration of all dense fogs was 2 hours and 59 minutes. The average of those that formed between midnight and noon was 2 hours and 39 minutes and of those that formed between noon and midnight was 6 hours and 15 minutes. These averages may be somewhat misleading, as four fogs that lasted more than 12 hours raised the average duration considerably. Of the 119 fogs, 76 lasted less than the average time of 2 hours and 59 minutes and 43 lasted longer. Slightly less than half of the dense fogs lasted less than two hours and 15 out of the 119 lasted less than one hour.

TABLE 6.—*Total number of times dense fog occurred during the different hours of the day at Lincoln, Nebr., during a period of 20 years*

Month	A. M.												P. M.												Total
	12-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	10-11	11-12	12-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	10-11	11-12	
January	2	3	3	3	4	4	9	11	15	12	6	3	2	2	1	0	0	0	1	1	1	1	1	2	87
February	3	2	2	2	2	2	10	14	14	14	6	5	4	4	2	1	1	1	1	3	3	3	2	2	103
March	0	2	2	0	2	1	3	7	7	3	2	0	0	0	0	0	0	0	0	0	0	0	0	0	32
April	0	0	0	0	1	1	2	3	3	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	12
May	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
June	0	1	2	2	0	1	3	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	12
July	0	0	0	1	1	1	3	5	4	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	17
August	0	0	0	1	1	1	2	3	3	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	13
September	0	0	0	0	0	0	11	15	14	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	47
October	0	0	0	0	0	0	4	5	5	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	16
November	0	0	2	2	1	1	5	5	11	8	2	1	0	0	0	0	0	0	0	1	1	2	2	1	45
December	0	0	0	0	0	0	1	3	8	9	4	0	0	0	0	0	0	0	0	0	0	0	0	0	25
Total	5	8	11	14	12	12	53	73	85	60	21	9	6	6	3	1	1	1	2	5	5	6	5	5	409

Table 6 gives the total number of times dense fog was recorded during the different hours of the day for each of the 12 months of the year and the total for the 20 years, and Figure 2 shows the total number of times dense fog was recorded during each hour of the day for the 20 years. These values must not be confused with the total number of hours of dense fog as given in Table 1, as Table 6 and Figure 2 represent the total number of times dense fog was recorded during the different hours regardless of the portion of the hour the fog prevailed. Dense fog was recorded in 409 hours, while fog actually prevailed a total of 354 hours and 33 minutes during the 20 years. Table 6 and Figure 2 probably give a better representation of the time of the day dense fog was most common than could otherwise be presented by means of a short table or chart.

Between 6 a. m. and 7 a. m. dense fog was recorded on 53 days, between 7 a. m. and 8 a. m. on 73 days, between 8 a. m. and 9 a. m. on 85 days, and between 9 a. m. and 10 a. m. on 60 days during the 20 years.

The hours between 2 p. m. and 7 p. m. were fairly free of dense fog. On only three days during the 20 years did dense fog occur between 2 p. m. and 3 p. m., and on only one day between 3 p. m. and 4 p. m., one day between 4 p. m. and 5 p. m., and one day between 5 p. m. and

6 p. m. Dense fog occurred on two days between 6 p. m. and 7 p. m.

The foggiest time of the day was between 7 a. m. and 9 a. m., when dense fog was recorded in 158 hours, or 39 per cent of the total number of hours in which dense fog was recorded. From 7 a. m. to 10 a. m. dense fog was recorded in 218 hours, or 53 per cent, and from 6 a. m. to 10 a. m., 271 hours, or 65 per cent.

Dense fog was recorded least frequently between 3 p. m. and 6 p. m., during which time it occurred in only three hours during the 20 years. From midnight to noon dense fog was recorded in 363 hours, or 89 per cent of the hours in which dense fog occurred, and from noon to midnight in 46 hours, or 11 per cent.

Figure 3 shows the actual time of every dense fog that was recorded during the 20 years, by months. The entry "DNA" means dense fog was first observed at 5.30 a. m., and these fogs were considered as beginning at 5 a. m. It is realized there may be some error in considering these fogs as beginning at 5 a. m., but in most cases the error is small.

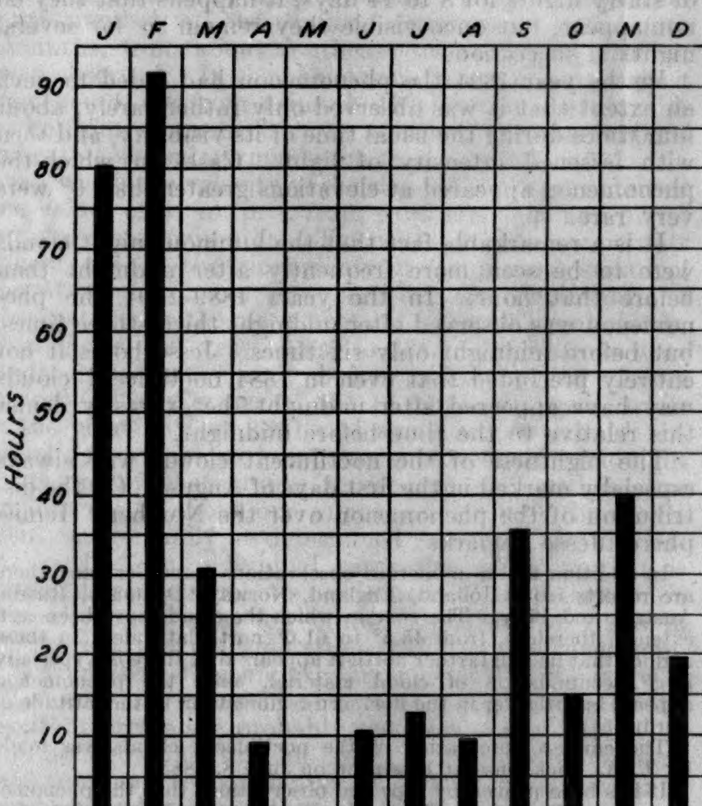

FIG. 1.—Total number of hours of dense fog for each month for the 20 years 1908 to 1927 at Lincoln, Nebr.

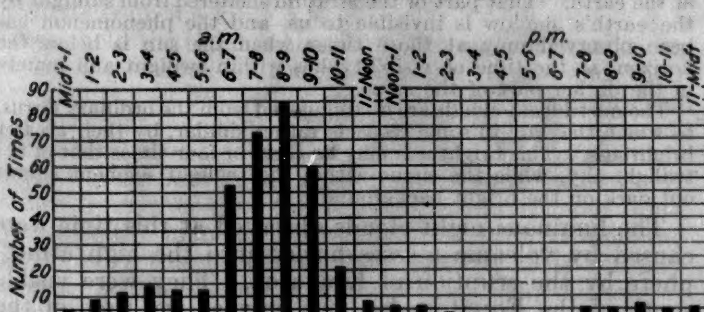

FIG. 2.—Total number of times dense fog occurred during the different hours of the day at Lincoln, Nebr., during a period of 20 years

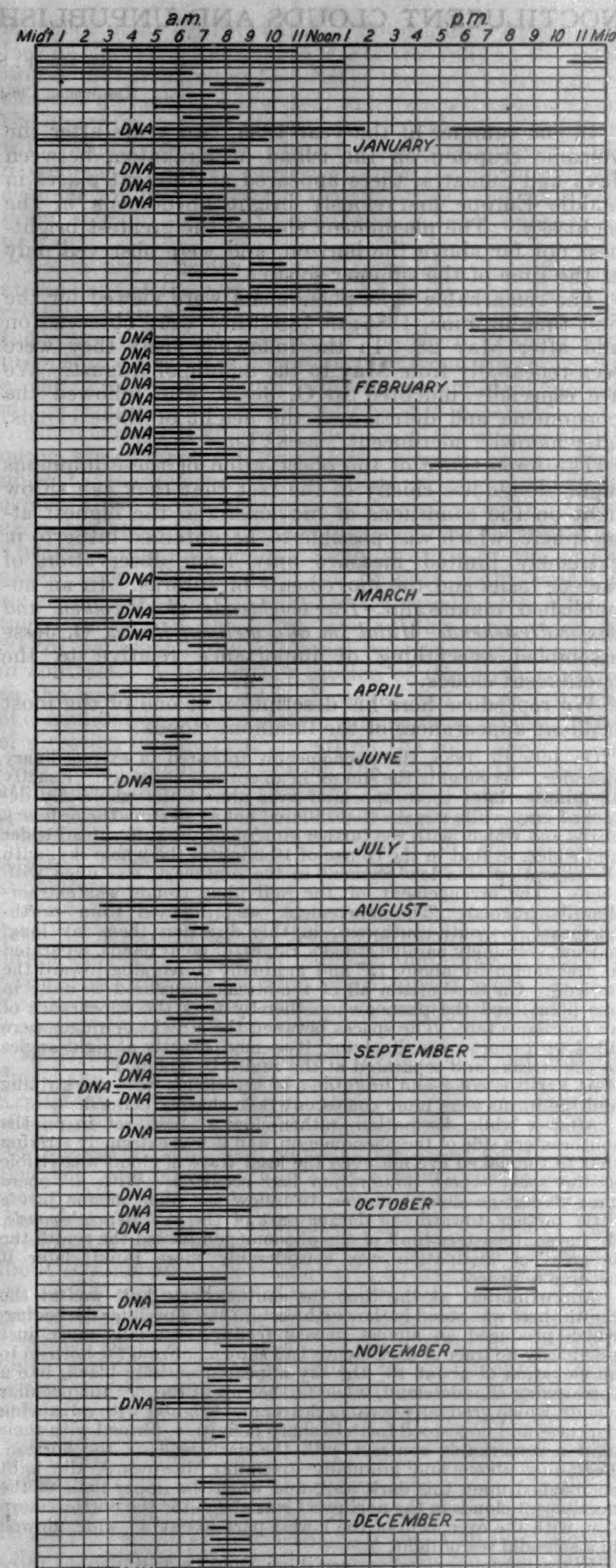

FIG. 3.—Hours of the day, by months, that dense fog prevailed at Lincoln, Nebr., during the 20 years 1908 to 1927, inclusive. DNA signifies during night after midnight

NOCTILUCENT CLOUDS AND UNPUBLISHED MEASUREMENTS OF THEIR VELOCITY

By Dr. F. S. Archenhold

[Das Weltall. 10-11 Heft. 1828. Berlin]

In the summer of the year 1885, two years after the volcanic eruption on the island of Krakatoa, between Java and Sumatra, there appeared at different places in middle Europe marvelously bright phenomena in the night sky. The phenomena showed the greatest brightness not far above the horizon, and were observed only at the time of the summer solstice.

The remarkable light phenomena were viewed for the first time in June, 1885; in 1886 they were observed on and after May 28. In the following years they were seen repeatedly from May to the middle of August. We are especially indebted to O. Jesse, who followed the phenomena and determined the height of these clouds, later named "noctilucent," as 82 km.

The importance of the observation of these luminous night clouds lies chiefly in the fact that they can throw light on the conditions of movement in the highest atmosphere, which was possible to be obtained hitherto in extremely limited measure only from observation of meteor trails and the movements of auroras. In an unpublished manuscript, *Die leuchtende Nachtwolken und das widerstehende Mittal im allgemeinem Raum*, O. Jesse assembled everything of importance relative to the noctilucent clouds.

We reproduce here his description of one of the most brilliant appearances of the luminous clouds:

On July 19, 1885, the phenomenon appeared in extraordinary splendor. At Steglitz the sun set in an entirely clear sky. Exactly 15 minutes later there appeared over almost the whole sky detached gray-white streaks that differed not at all from the ordinary cirrus and which, with the further sinking of the sun, spread wider and wider, so that in the course of 10 minutes the whole sky, with the exception of a low segment in the southeast, was filled with them. The arrangement of the individual clouds was extraordinarily regular. The movement was directed from north-northeast to south-southwest; in this direction there lay long, narrow, seemingly parallel streaks, ridges, or polar bands, separated at the zenith by about 12° and gradually converging toward the horizon. On the horizon all of the streaks appeared to unite in one point, and the phenomenon thereby took the appearance of an enormous fan. The spaces between the streaks or ridges were filled with short cross ribs lying, it seemed, exactly at right angles to the streaks and separated at the zenith by about 5°.

At first the color and brightness of the clouds were not striking and the forms were more coalescent than sharply defined.

After a while dissipation, rather slow at first, set in on the southeastern side of the phenomenon, and it was extremely striking that to the naked eye not even the least trace of cloud was visible in the space where obliteration had occurred. With an opera glass it was possible, however, to follow the phenomenon just a little farther toward the darker part of the sky (*Nachthimmel*). As the southeastern limit of the phenomenon passed the zenith the progress of dissipation was considerably more rapid; later it became retarded.

Approximately at the time the southeastern limit was at the zenith there was noted in the northwestern sky a peculiar darkening, which produced an almost uneasy feeling, especially since just previously no trace of dark clouds had shown. From the horizon to an elevation of about 10° the sky appeared entirely black, like a threatening thundercloud, while farther up in the sky the peculiar clouds, which gradually became clearer and brighter with advancing darkness and now stood forth in sharp definition, formed with their light a remarkable contrast with the dark wall on the horizon. Beginning above and gradually extending downward, the light encroached upon this dark wall, and when the upper limit of the noctilucent clouds in the northwest was about 15° the northwestern sky, with the exception of the lowest part about 4° wide, glowed in a splendid sea of light.

In the luminous cloud surface there could be distinguished three horizontal strata. The lowest stratum, hidden in greatest part from the horizon to an elevation of 4° by houses and trees, had a dull reddish-yellow aspect; the second stratum immediately above gave forth a splendid blue-white, silver light; the upper stratum shed a light that was similar but somewhat less brilliant, and stood sharply delineated against the night sky. The boundaries between the strata were not sharp; there was a gradual transition. The contrast shown to the adjacent night sky by the bright middle stratum appeared to be the same as that shown to the immediately adjacent sky by the nearly full moon when it is at an elevation of about 10° in the eastern sky at or just after sunset.

In a manner similar to that observed on this evening the phenomenon manifested itself in the following years, yet from year to year there was a continual decrease in intensity. Moreover, it is to be mentioned that even in the first years it was not very frequently of the same extent and splendor as on this evening. Phenomena of lesser brilliance were rather frequent in the first year, on an average about two or three times in each week.

The noctilucent clouds appear only at the time of the summer solstice and only with clear sky, then not in every part of the sky, but only in the twilight segment. They are not visible, however, on every summer night, when they really might be expected. Despite the continuance of starry nights for 8 to 14 days, it happens that they do not appear, but once visible they remain so for several nights in succession.

In the year 1894 the phenomenon had faded to such an extent that it was observed only rather rarely, about four times during the usual time of its visibility, and then with lessened intensity of light. Cases in which the phenomenon appeared at elevations greater than 6° were very rare.

It is a remarkable fact that the luminous night clouds were to be seen more frequently after midnight than before that hour. In the years 1889–1894 the phenomenon was observed after midnight thirty-three times, but before midnight only six times. Jesse holds it not entirely precluded that even in 1884 noctilucent clouds may have appeared after midnight; he expressly denies this relative to the time before midnight.

The bightness of the noctilucent clouas was alwavs especially marked in the first days of August. On the distribution of the phenomenon over the Northern Hemisphere, Jesse remarks:

In addition to the numerous observations from Germany there are reports from Holland, England, Norway, Denmark, Russia, Austria, and Italy. The zone in which the clouds have been seen extends, therefore, from 45.5° to 61.6° north latitude. In those regions that lie still farther north it appears that there is a specially large accumulation of cloud material, since the phenomenon appears far brighter in the northern regions than in the latitude of Berlin.

The earliest observation of the noctilucent clouds was made by T. W. Backhouse at Kissingen on June 8, 1885.

It has been proven by repeated observations that the phenomenon of noctilucent clouds is due to the sun's illumination of a stratum of foreign matter, which, in latitudes of about 45° to 64°, floats in the atmosphere at a distance of 82 km. from the surface of the earth. That part of the stratum sheltered from sunlight by the earth's shadow is invisible to us, and the phenomenon has been observed only at those times when the sun is below the horizon, so the time of visibility lies within twilight and mainly in the darker part of the same.

The noctilucent clouds are distinguished from the ordinary cirrus, to which they are in some respects rather similar, by their greater brightness. This brightness may be three or four times that of the twilight sky, while the cirrus within the twilight segment stands out dark on the bright background.

The luminous night clouds observed at this time were caused by volcanic masses hurled into the high atmosphere by the eruption of Krakatoa. They were visible south of the Equator also, but only at the time of the summer solstice of the Southern Hemisphere.

On the outward form and movement of the phenomenon Jesse writes as follows:

The variability in the cloud forms is generally great. In the photographs, part of which are separated by an interval of only five minutes, it is a rather rare case that the same cloud points are present in two views. In general the form on the second photograph, although similar to that on the first, is entirely different in detail. I sought to determine the movement of the noctilucent clouds by directing my eye to a definite point. However, it was possible only once in a while to keep the same point with the eye longer than two or three minutes.

When photographs are taken at intervals shorter than two minutes, as by F. S. Archenhold for the purpose of determining movement, corresponding points are, as a rule, present in two views; yet it happens, especially for high elevations, that this is not the case.

The direction of movement of the noctilucent clouds is often variable on different days. It has been possible, however, to ascertain that the movements after midnight are subject in a special way to a definite law, while before midnight this conformity to law appears in a form somewhat different. The velocity is, as a rule, subject to marked changes, but on an average it is greater after midnight than before that hour. After midnight velocities lie between 25 and 200 m.p.s., while before midnight they vary from zero to 85 m.p.s.

The results of measurements given in the tables [1] show remarkable peculiarities with reference to velocity and direction of the noctilucent clouds. Despite the rather large number of observations, movement from south azimuths, from about southeast to southwest, has not been observed. In the phenomena before midnight most movements are from azimuth 48°; [2] in those after midnight from azimuth 63°. In addition, the observations indicate a secondary maximum from azimuth −73°.

For the mean velocity of the clouds there were obtained the values of 31 m. p. s. from west azimuths and 67 m. p. s. from east azimuths. The conformity to law permits conclusions on the movements in the highest strata of the atmosphere, and just here lies the significance of observations on the movements of the noctilucent clouds. During the first years, 1885 to 1887, observations were made in Germany only before midnight and almost entirely with reference to the 16-point wind rose, while in the years 1889 to 1891 and again in 1894 the determinations were carried out almost always after midnight by means of photographs succeeding one another after an interval of about one minute. Although the movement can generally be determined rather well by the latter method, in individual cases the accuracy that is obtained leaves much to be desired. The phenomenon generally remains at low elevations, up to 10°, and in this region the determinations can be only uncertain. However, the rather uniform arrangement of the individual values of a group of observations indicates that the resultant errors are probably not very considerable. It is to be mentioned that all points of a pair of views have been combined for a mean value, so that the uncertainty has been reduced considerably. The distance between the streaks or ridges appears to be always approximately the same. The mean distance between wave lines varies but little from 9.4 km.

Jesse held the opinion that both the seasonal variations in the appearance of the noctilucent clouds and their movements can be readily explained by the assumption of a resisting medium in the space of our solar system. He assumed that this resisting medium is not at absolute rest but takes part in the motion of the solar system. It follows from this that the resisting medium itself must have, like the planets, a direction of motion around the sun. Under this condition there can be, as is actually the case, no manifestation of hindrance to the motions of the planets. Only in the case of the comets, with their great inclinations and partly retrograde motion, may an influence make itself eventually noticeable. At the surface of the earth the atmosphere shares fully in the rotation of the earth, but at the limit of the earth's atmosphere this will no longer be the case; so between the surface and the upper limit of the atmosphere the velocity of rotation will gradually decrease. In the vicinity of the earth this movement is not to be observed, since the meteorological currents are predominant. On the other hand, at elevations of over 30 km. an east-west current appears to prevail.

Let us first consider the velocity which a cloud floating at the limit of the earth's atmosphere will appear to have relative to an observer on the earth. Since in our latitudes the rotational velocity of the earth is about 250 m. p. s. in a west-east direction, then from the viewpoint of the observer the clouds will have an apparent motion at the same velocity, but in the opposite direction.

Since nothing is known in advance of the motion of the outer atmosphere (*Weltraumluft*), several assumptions must be made here. Observations of the noctilucent clouds have shown that the rotational velocity of the earth can be recognized in the movements of those clouds. The other motions of the earth relative to the outer atmosphere (*Weltraumluft*) can be only slight, since if we should take the relative velocity equal to the revolutional motion of the earth around the sun, which is 30 km. per second, the rotational velocity must disappear in contrast. A translatory motion of the earth relative to the resisting medium is, however, not to be left out of consideration, since the observations show a dependence of direction of cloud movement on the solar apex. The noctilucent clouds are not at the limit of the earth's atmosphere, since their average velocity from the east is not 250 m. p. s., as it must be in that case, but only a fractional part thereof. The height of the limiting stratum must be, on the contrary, several hundred kilometers.

Jesse set forth these interesting considerations in detail in his manuscript. As to the nature of the noctilucent clouds, he held the opinion that they are to be referred to gas masses that were hurled aloft by the Krakatoa eruption and have permanently condensed at a constant height.

Later pursuit of the luminous night clouds shows that they have been visible from time to time even after the Krakatoa eruption. Here, also, the phenomena are often to be related with volcanic eruptions. It is possible, moreover, that solar activity possesses an influence over the phenomena. There were numerous large sun spots when the noctilucent clouds were observed in the years 1908, 1917, and 1918. Lately Jardetsky has advanced a new theory. He points to the fact that at about 70 kilometers above the earth hydrogen and oxygen are found in the ratio of approximately 2 to 1 (oxyhydrogen gas). He believes that under the influence of electrons emitted from the sun there form ice crystals which shine with reflected light. In any event, it can be said that the clouds must be attributed to the presence of foreign matter at these heights, hurled there by volcanic eruption, formed there under the influence of solar raditation, or transported there from without. Their connection with twilight anomalies, which occur for the most part after volcanic eruptions, confirms this opinion. At the passage of the earth through the train of Halley's comet in the year 1910 an optical disturbance was plainly noticeable.

The passage through the train of the comet took place during the night of May 18–19, 1910. The twilight disturbances began on May 18 and reached the maximum

[1] Not reproduced here.

[2] Azimuth reckoned from north; positive toward east, negative toward west.

on May 19. Possibly the noctilucent clouds photographed by myself in 1910[3] are to be attributed to foreign matter carried in by Halley's comet.

With the noctilucent cloud at a constant height there exists a relation between the distance of the sun below the horizon and the zenith distance to which the clouds are visible; they remain bright so long as they receive the direct light of the sun. The values for 1910[4] conform to the relation derived by Jesse for noctilucent clouds as well as might be expected.

It may be stated that in this case also the noctilucent clouds had an elevation of some 80 km., although no direct determinations from two stations are available. During the time of photographing, the sky was entirely clear, with no artificial light on the horizon. The direction of the cloud streaks or ridges was northwest to southeast and the direction of movement the same. The west-east component of velocity was somewhat above 20 m. p. s. On July 17, 1910, after a wonderful red sunset, I saw at about 10:05 p. m. noctilucent clouds extending up beyond Capella. At 10:15 p. m. the brightest streak was prolonged in a southerly direction and another streak had become visible to the left and below. After 10:35 p. m. the streaks were no longer visible in the clear sky.

Doctor Korn reported to me by letter on an observation made at the same time. With Lieke he observed at Wongrowitz (52° 48′ N., 17° 22′ E.) on June 24, 1910, at 11 p. m., noctilucent clouds in the north—cirrus forms that shone with silver light up to 1.5° below Capella, which was almost exactly north. From north they extended 15° to the east and 30° to the west. Doctor Korn observed the optical disturbances of May 19–25, 1910.

Information on the years in which noctilucent clouds have been observed is given in *Beiträge zur Kenntnis der Dämmerungserscheinungen und des Alpenglühens* by P. Gruner (Zurich, 1925). There is, however, no reference to the observations in June, 1910.

Since the noctilucent clouds will certainly return, I hope that through the above details the interest in these phenomena will be revived.—*Translated by W. W. Reed.*

[3] 6 reproductions accompany the original text. [4] Table not reproduced here.

NOTES, ABSTRACTS, AND REVIEWS

THE MAGNETIC STORM AND AURORA OF JULY 7–8, 1928

An unusually extensive auroral display was observed over nearly all parts of the country on the night of July 7–8. This display was noted locally from the northern border to the Rio Grande and in central Florida, and from the Atlantic to the Pacific. At many points the display was indicated as being of unusual brilliancy, and its effect on wire communications was distinctly noticeable, some stations reporting that on account of clouds the manifestation was not visible, but its presence was reliably indicated by wire troubles.

In some sections it was reported as being the first auroral display ever observed in a midsummer month. Following are several reports of this auroral display.—*P. C. Day.*

London, England.—A magnetic storm, accompanied by a display of the aurora borealis, took place during the night of July 7 and morning of July 8. The magnetic disturbance reached a maximum between 1 and 2 a. m. on July 8. About this time, also, the horizontal force and vertical force traces went off the recording sheets. The ranges of these two elements exceeded 500 during the storm. This magnetic storm is probably the largest recorded at Greenwich since that of May 13–17, 1921—it is certainly the largest since that of October 15–16, 1926.

At the time of this recent storm there was a moderate-sized group of sunspots just past the sun's central meridian. Possibly spectroscopic observations which may have been made of this group will show it to have been unusual. There was a much larger group on the disk at the time, but this was a considerable distance east of the central meridian. The sun's general activity shown by the spots has been increasing during the last few weeks.—*Nature, London, July 21, 1928, p. 108.*

Worcester, Mass.—I first saw the display at 9 p. m., when it covered virtually the entire sky down to about 10 above the SSE. horizon. This part of the display, from 9 to 9:15, was one of considerable brilliance and was marked not only by its extensiveness and the auroral corona but also by large patches of intense red or green. The exceedingly clear air and sky favored a fine view of the display. Immediately after this bright phase, from 9:15 to 9:30, there were four distinct arches, two overhead and two in the north, while two in the southern sky had faded but could still be distinguished. At 10:15 the display was still extensive but not so bright.

At 10:40 the display was entering on another stage of great brightness, color, and extent. Colors appeared at 10:45, rapidly becoming bright. The greens carried the most light, while the reds, varying from crimson to fire glow, were rich in tone. The display again extended far into the south down to within about 10 of the horizon, the southernmost arch being very bright. The corona formed brilliantly overhead and to the SSE. of the zenith. The total light was sufficient for reading. At 10:52 the display began to flicker. There was considerable motion in the corona.

From 10:55 to 11 a steady, progressive motion of auroral lights across the zenith was noted and roughly measured as to angular velocity. The mean of four observations was 0.1 radian in 10 seconds. At a height of 100 km. this would mean a velocity of 1 km. per second. I assume that this motion may be taken to represent the wind at that great height.—*Charles F. Brooks, Clark University.*

Sheepshead Bay, N. Y., July 7–8, 1928.—I first noticed it at Sheepshead Bay right after sunset, Saturday night, in the form of what appeared to be a vivid greenish yellow cloud of sulphur smoke that suddenly grew in the eastern sky and quickly faded away. A captain of a fishing boat said he also noticed this phenomenon in the eastern sky while the sun was still above the horizon.

At 9:30 there gradually glowed into pronounced brilliance, halfway up in the southern sky, a broad bow of yellowish-white light which stretched completely from the eastern to the western horizon along the ecliptic. At 10 p. m. the characteristic aurora borealis sheets, streamers, bands, and rays, red, green, yellow, white radiated from the zenith to the northeast horizon. It had faded by 11 p. m. with the exception of a few faint rays in the northern sky.

About 2:30 a. m. auroral streamers again began to grow in the northern sky, and by 3 a. m. and until dawn the sky was resplendent with as brilliant an aurora borealis as is seen in this vicinity. It blazed, sizzled, pulsated, seethed, and flashed with an awesome brilliance in all the colors of the rainbow.

At times the entire northern sky rippled with what appeared to be moonlight on ocean billows or licking white flames. And New York slept during this glorious celestial commotion!—*E. E. Cockefair, Brooklyn, N. Y.*

Aurora cuts off Winnipeg from the world.—WINNIPEG, MANITOBA, *July 9.*—Electric storms, torrential rain, and aurora borealis have combined to disrupt the normal life in the central areas of Canada during the last 24 hours.

For the greater part of the forenoon Winnipeg had only partial telegraphic communication with the outside world, while both railway and highway travel was hard hit by a rain of cloudburst proportions.

Telegraphic services were affected by the violent play of the mysterious northern lights across the entire continent. Advices received here were that the interruption was one of the most widespread in years. Commercial and private wires, however, were not so hard hit as press lines.

Railway schedules were delayed on the main line of the Canadian Pacific Railway as the result of a cloudburst near Ingolf, Ontario, which washed out much trackage and derailed a freight train of 22 cars. Another freight train derailment at Biscotasing, Ontario, east of Chapleau, brought down many telegraph poles and disrupted communication east and west.

According to an official statement issued by the Canadian Pacific officials, all trains over the main line will be rerouted over Canadian National routes. It is expected that about 26 hours will be required to repair the damage to the tracks in the cloudburst zone.

Rainfall ranging from more than 1 to 3.28 inches was reported in points on the prairies.

Little Rock, Ark., July 7–8, 1928.—The aurora was first noticed about 9:30 p. m. of the 7th. By 10 p. m. it was very bright, a perfect arch being visible. No clear sky was visible below the arch, however, as is usually seen farther north. Just the upper portion of the arch rested on the horizon. It continued a large portion of the time until the morning of the 8th.

The red and old-rose colored haze was very prominent during the early part of the display, great banks of haze to the east and west of the North Star, with the beams passing slowly from west to east. The beams moved much slower than usual. Later the colors faded, leaving mostly white light. Stars could be plainly seen through the aurora, even through the dense banks of haze where the brilliant colors occurred. The beams extended nearly to the zenith at times.

This was decidedly the brightest aurora seen in Arkansas in the past 14 years.—*H. S. Cole, Weather Bureau.*

Little Rock, Ark., July 7–8, 1928.—One of the most brilliant displays of the aurora borealis, or to those who find such pronunciation tests difficult, the northern or polar lights, ever seen in Arkansas illuminated the northern horizon Saturday night.

So pronounced was the phenomenon, which is seldom clearly seen except in the Middle or Northern States, that the attention of hundreds of people was attracted to what was believed by many to be the reflected glow of a monster fire in the north.

The display was definitely identified by H. S. Cole, local meteorologist, as the aurora borealis, and the phenomenon was the brightest he could recall having been seen this far south. The polar lights are often seen in the far Northern States, Mr. Cole said, but in the past 14 or 15 years he could recall such display on only two or three previous occasions. At none of these times, he said, were the lights so pronounced.

Viewed last night, the northern lights, first coming into distinct view for minutes at a time and then fading entirely from sight for a brief period, seemed to assume green and slightly pink tinges, the green next to the horizon.

CALLERS BESIEGE DEMOCRAT

Dozens of calls were received by the Arkansas Democrat from persons who believed the glow to come from a great fire in the north. Calls were also received from various towns in other parts of Arkansas, where undoubtedly the polar display was more pronounced than in Little Rock because of the fact that the lights of this city so illuminated the sky that there was considerable interference with the view. One long-distance call came to the Democrat from Bigelow, where excitement was running at high pitch over what was believed to be signs of a devastating fire at Morrilton, away to the north. Conway was among the other towns which sought information from the Democrat.

One of the peculiar effects of the phenomenon, believed to be occasioned by the passage of electricity through the upper regions of the atmosphere, is interference with wire communication, particularly the telegraph, and several instances of such interference were reported Saturday night. Some cases of radio interference were also believed to have resulted from the polar demonstration.

The aurora borealis usually manifests itself by streams of light ascending toward the zenith from a dusky line of clouds or haze a few degrees above the horizon, and stretching from the north toward the east and west so as to form an arc with its ends on the horizon. The different rays of the display were clearly seen—are constantly in motion. Sometimes it appears in detached places; at other times it may cover practically the entire sky. It assumes many shapes and a variety of colors.

What are known as magnetic storms almost inevitably accompany the exhibitions of the aurora.—*Arkansas Democrat, Little Rock, Ark.*

Newport, N. H.—While stopping at Newport, N. H., the aurora of the evening of July 7, 1928, was called to my attention at 10 o'clock. At that time the entire sky looked as if covered with an irregular layer of thin, luminous clouds, changing and pulsating. Faint rose-colored tints were observed, especially in the south, but the general color as I saw it was whitish. There was no auroral arch, and no streamers were seen to rise from any point above the horizon. Overhead I noted a slight convergence of luminous waves about 2° south of the zenith. At 11 o'clock, when last observed, the phenomenon had faded to a great extent.—*Willis E. Hurd.*

Chesterbrook, Fairfax County, Va., July 7, 1928.—The aurora was first seen at 8:50 p. m. Near the horizon it covered from azimuth 105° to 255°. Above the Pole Star it reached up to 70° altitude. It seemed to be veiled by thin, even clouds; color very light yellow or pure white; appeared evenly diffused, without flashing or shifting motion. Last seen at 9:30 p. m.—*Herbert C. Hunter, Climatological Division, Weather Bureau, Washington.*

The International Commission for Synoptic Weather Information.[1]—The meeting of the International Commission for Synoptic Weather Information that was held in London during the week May 29 to June 2, 1928, marked another step in the progress toward the ideal of the world weather map. The last previous meeting of the commission was held at Zurich in September, 1926. Meanwhile the International Radio Telegraph Conference had met at Washington in the autumn of 1927.

[1] Abstracted from a report by Lieut. Col. E. Gold, F. R. S., in Meteorological Magazine for August, 1928, London.

Progress toward the ideal program in collecting synoptic weather reports was made when the International Telegraph Conference at Paris gave international priority to meteorological messages, and further assistance was rendered by the grant at Washington of the same priority with respect to radio messages.

Even more important from the point of view of synoptic meteorology in Europe was the resolution of the Washington conference that two wave lengths should be reserved for use in Europe in the distribution of collective synoptic reports.

The Synoptic Commission had to decide whether each country issuing collective synoptic reports should be asked to adopt one or other of these two wave lengths, or whether the existing scheme for the exchange of reports in Europe should be replaced by a different one.

Under the new plan proposed by the commission the reports from all the countries of western Europe would be issued from a wireless station in one of the reserved wave lengths in France; those from the rest of Europe, excluding Russia and the Balkans, would be issued from a station in Germany on the other reserved wave length. The reports from Russia and Siberia would be transmitted from an existing station whose wave length is already fixed and is different from the wave lengths for the rest of Europe.

The second important question considered by the commission was that of arranging for the synoptic representation of the oceans. A special subcommittee had been appointed at Zurich to consider the method of collecting and distributing oceanic reports. The subcommittee met in Paris in May, under the chairmanship of General Delcambre, Director of the Meteorological Office of France, and prepared a scheme for the consideration of the commission. The commission gave its approval of the scheme which includes the collection of reports from all ships at a selected wireless station and for the repetition of the reports received for the benefit of all countries. It is anticipated that one collecting and distributing point will be at the Azores.

The scheme further provides for the reports to be made in a universal code and for the observations to be made at standard hours of Greenwich time in all oceans. * * *

Action was also taken looking toward further revision of the International Code for use in telegraphic reports, in order to extend its use to regions outside of temperate zones and to give an adequate description of the weather in all lands, the new code to be submitted to meteorological services in all countries for their consideration preliminary to a decision being taken at a future meeting of the conference and committee.

Finally, the commission voted that in synoptic messages transmitted by wireless telegraph for international exchange the pressure will be expressed in millibars, and a subcommittee was asked to "consider the question of the unification of reports of temperature in international messages on the basis of the centigrade scale."

The meeting was attended by the Chief of the Weather Bureau and Mr. Calvert, of the forecast division.

Tornado in Wyoming, June 29, 1928.—A small tornado wrecked seven buildings on a ranch near Gillette, Wyo., on June 29, 1928. Mr. H. R. Johnson, cooperative observer at Gillette, observed the storm and saw four funnels pendent from the cloud. He also made a photograph of it, which has been sent to the editor. The cloud was evidently some distance from the camera; one funnel is clearly shown, and there is evidence of two others, but the image of them is too indistinct to stand reproduction.

In Colonel Finley's tornado reports of the early eighties, drawings showing more than a single funnel cloud are rather common, but the photograph in question is the first one the editor remembers to have seen that showed more than a single funnel pendent from the cloud.—*A. J. H.*

Meteorological summary for Chile, June, 1928 (by J. Bustos Navarrete, Observatorio del Salto, Santiago, Chile).—Cyclonic activity was marked during the first half of the month, but thereafter it showed a gradual decrease in frequency. The paths of the depressions had a progressive movement toward the south. Important depressions crossing the southern region: 3d–6th, precipitation from Coquimbo to Magallanes (24-hour amounts of 2.35 to 3.55 inches in the middle region); 8th–11th, excessive rains (6.97 inches at Valdivia on the 9th) and rough weather (north winds with velocities of 37 to 56 miles per hour between Arauco and Chiloe, also on the 9th); 14th–15th, precipitation north as far as Aconcagua; 16th–18th, heavy winds and rain; and 19th–21st, heavy precipitation (2.35 inches in 24 hours at Valdivia). Depressions appeared off the middle coast on the 1st and off the southern coast on the 27th; the former caused rainfall from Coquimbo to Chiloe and the latter brought unsettled weather and general precipitation, ending on the 30th.

Important anticyclones, accompanied by fair, cool weather: 1st–3d, movement from southern Chile to northern Argentina; 7th–9th, movement from Juan Fernandez Islands across middle Chile toward central Argentina; and 22d–27th, the longest period of fine weather, slow movement from Juan Fernandez Islands to Chiloe and thence to Neuquen, Bahia Blanca, and Buenos Aires.

The region receiving rainfall extended from Copiapo to Magallanes. The total precipitation for June was 5.94 inches at Santiago and 25.39 inches at Valdivia.—*Translated by W. W. Reed.*

Meteorological summary for Brazil, June, 1928 (by Francisco de Souza, Acting Director, Directoria de Meteorogia, Rio de Janeiro).—Atmospheric circulation was abnormal, due to the entrance of seven anticyclones and the activity of the continental depression and those of higher latitudes. Most of the anticyclones weakened in moving northeast, and the weather in the region north of the parallel of 25° was less unsettled than it usually is at the season.

In the northern and central regions precipitation was light, 0.70 to 2 inches below normal, but in the southern region it was extremely abundant, averaging 2.70 inches above normal. The rainy weather interfered with preparation of soil and planting and harvesting of cereals in different parts of the extreme south. In the tobacco and cane areas of the central region and in the cotton areas of the northeast the weather was unfavorable on account of lack of rain. Harvesting of cotton, cane, coffee, tobacco, and cereals was under way.

At Rio de Janeiro the weather was alternately fine and unsettled, with less than normal cloudiness. The mean temperature was 3.2° above normal; the highest temperature was 90° on the 7th and the lowest was 51° on the 12th. The extremes for the Federal District, both recorded at Campo dos Affonsos, were 95° on the 6th and 49° on the 11th. Precipitation was deficient, measureable amounts on three days totaling 2.20 inches. Relative humidity was rather low, 2 per cent below normal. The prevailing south winds were fresh at times. The maximum wind velocity was 47 miles per hour from the west on the evening of the 8th.—*Translated by W. W. Reed.*

BIBLIOGRAPHY

C. FITZHUGH TALMAN, in Charge of Library

RECENT ADDITIONS

The following have been selected from among the titles of books recently received as representing those most likely to be useful to Weather Bureau officials in their meteorological work and studies:

Abbot, Charles G.
Weather and radiation. p. 485–500. 24½ cm. (Yale review. v. 16, Apr., 1927.)

Angervo, J. M.
Einige Formeln für die numerische Vorausbestimmung der Lage und Tiefe der Hoch- und Tiefdruckzentra. Helsinki. 1928. 45 p. figs. 25 cm. (Annales Acad. sci. fenn. Ser. A. T. 28, N: o 10.)

Ångström, A., & Nauclér, O.
Instruktion för pilotballongviseringar och deras beräkning. Stockholm. 1928. 15 p. illus. plates (fold.) 24½ cm. (Stat. met.-hydrog. anst. N: r 270.)

Antevs, Ernst W.
Last glaciation with special reference to the ice retreat in northeastern North America ... New York. 1928. x, 292 p. illus. (maps) diagrs. (part fold.) 21 cm. (Amer. geogr. soc. Research series no. 17.)

Carton, P.
Note sur le climat de l'Indochine. Hanoi. 1928. 45 p. plates (part fold.) 27½ cm. (Extr.: Feuille men. de renseigne. de l'inspec. gén. de l'agric., de l'elevage et des forêts. Fév., 1928.)

Cline, Isaac Monroe.
Floods in the lower Mississippi valley. n. p. n. d. 28 p. figs. plate (fold.) 23½ cm.

Entwistle, F.
Fog. London. 1928. 43 p. illus. 25 cm. (Aeronautical reprints. no. 28.)

Eredia, F.
I meteorografi negli aeroplani. Pisa. 1928. 23 p. illus. 25 cm. (L'Aerotecnica. Giorn. ed atti dell'Ass. ital. di aerotec. Anno 7, no. 2. 1928. A. 6.)
La temperatura e l'umidità dell 'atmosfera desunte dai sondaggi con palloni frenati e con cervi volanti eseguiti a Vigna di Valle (Roma). Roma. 1928. p. 85–89. fig. 29½ cm. (Atti Pont. accad. sci. Nuovi Lincei. Anno 81. Sess. I del 18 Dic. 1927.)

France. Office national météorologique.
Météorogrammes synoptiques. Liste des stations météorologiques figurant dans ces météogrammes. Paris. 1928. 31 p. 27 cm.

Geiger, Rudolf.
Messung des Expositionsklimas. no. 1–5. Berlin. 1927–28. 25 cm. (Forstwissensch. Centralblatt. 49–50 Jahrg.)

International union of geodesy and geophysics.
Troisième assemblée générale réunie a Prague du 3 au 10 septembre 1927. Toulouse. 1927. 117 p. 25½ cm. (Cons. internat. de recherches.)

Italy. Min. della regia aeronautica. Aviazione civile e traffico aereo.
Comunicazioni presentate dall 'Ufficio presagi al IV congresso internazionale di navigazione aerea. Roma. 1928. 34 p. illus. 24½ cm. (Estr.: v. 2 Rendiconti del 4 cong. di navig. aerea, tenuto a Roma dal 24 al 30 ott. 1927.)

Italy. Servizio idrografico.
Carte quinquennali delle precipitazioni atmosferiche in Italia. Fasc. 1. Quinquennio 1921–1925, by Filippo Eredia. Roma. 1928. xii, 94 p. plates (fold.) 34 cm.

Japan. National research council. Committee on Pacific oceanography, comp.
Records of oceanographic works in Japan. Tokyo. 1928. 55 p. illus. plates (part fold.) 25 cm. (v. 1, no. 1. March, 1928.)

Judson, E. B.
Automatic recorder for measuring the strength of radio signals and atmospheric disturbances. p. 666–670. figs. 23 cm. (Repr.: Proc. Inst. radio engin., May, 1928.)

Kaigorodov, Alexis J.
Climate atlas of White Ruthenia. Mensk. 1927. 13 p. 78 charts. 35½ cm. [Author, title and text in English, Russian and White Russian.]

Kalitin, N. N.
Sur la variation de l'intensité totale de la radiation solaire pendant l'éclipse du soleil du 29 juin 1927. p. 61–64. 27 cm. (Comp. rend. l'Acad. sci. de l'URSS. 1928.)

Loveridge, E. F.
Effect of land elevation upon rainfall of Hawaiian Islands. p. 311–318. illus. 26 cm. (Mid-Pacific. v. 35, April, 1928.)

Lumby, J. R.
Surface sampler, an apparatus for the collection of samples from the sea surface from ships in motion. With a note on surface temperature observations. p. 332–342. figs. 25½ cm. (Extr.: Journ. du cons. inter. pour l'explor. de la mer. v. 2. no. 3. 1927.)

Meyer, Rud.
Die Lichterscheinungen der Atmosphäre und ihre Beobachtung. p. 145–164. figs. 26 cm. (Sonderab.: Korrespondenzblatt des Naturforschervereins zu Riga. Bd. 59. 1927.

Meyer, R., & Bauman, G.
Beiträge zur Klimakunde des Ostbaltischen Gebietes. 1. Mittelwerte der Temperatur 1886–1910. p. 165–180. charts. 26 cm. (Sonderab.: Korrespondenzblatt Naturforschervereins zu Riga. Bd. 59, 1927.)

Murphy, Howard C.
"Menace of dust." n. p. n. d. 6 p. 28 cm. (Reprint.) [Manifolded.]

Östman, C. J.
Instruktion för sonderingar med flygplansmeteorograf. Stockholm. 1928. 15 p. illus. plates (fold.) 24½ cm. (Statens met.-hydrog. anstalt. N: o 267.)

Pollak, Leo Wenzel.
Charakteristiken der Luftdruckfrequenzkurven und verallgemeinerte Isobaren in Europa. Prag. 1927. 58 p. illus. plates. tables. 31½ cm. (Prager geophysikalische Studien. I.) Čechoslovakische Statistik. Bd. 44. Reihe XII (Landwirtschaft, H. 6.))

Prinz, Gyula.
Beiträge zur Glaziologie Zentralasiens. Die Pleistozäne Vergletscherung des Zentralen Tienschan, des östlichen Pamir und westlichen Küenlun sowie die postglazialen Klimaveränderungen. Budapest. 1927. p. 131–335. illus. plates (part fold.) 26½ cm. (Mitteil. Jahrb. kgl. Ungar. geol. Anstalt. XXV. Bd., 5. (Schluss-) Heft.)

Rouch, J.
La température et les courants de la mer dans l'Antarctide américaine. Monaco. n. d. 7 p. fig. 25½ cm. (Bull. de l'Inst. océan. N° 520. 4 juil. 1928.)

Scotland. Min. of agric. & fish., & bd. of agric. Agricultural meteorological scheme.
Report on agricultural meteorological conference. 1927. Held at the Meteorological office, South Kensington, S. W. 7. on September 22nd and 23rd 1927, under the chairmanship of Sir. W. Napier Shaw, F. R. S. n. p. n. d. 86 p. figs. plates. 33 cm.

Selga, Miguel.
Astronomical and meteorological conditions of the eclipse of the sun, May 9, 1929, in the Philippines. Manila. 1928. 24 p. figs. map (fold.) 29½ cm.
Evaporation of Manila. Manila. 1928. 15 p. fig. 29½ cm.
Intensity of rainfall at Manila. Manila. 1928. 27 p. figs. 29½ cm.
Sunshine of Manila. Manila. 1928. 22 p. figs. 29½ cm.

Shostakovich, V. B.
Contributions à l'étude du climat de la République Iakoute et des pays contiguës de l'Asie septentrionale. 2 v. Leningrad. 1927. Text. ii, 156 p. Atlas. 25 plates. 30 cm. (Acad. sci. de l'Union Rép. Soviétiques socialistes. Trav. Comm. pour l'étude de la Rép. autonome Soviétique socialiste Iakoute. T. 6.) [Author, title and text in Russian and German.]

Teesdale, L. V.
Tornado-resistant construction of buildings possible by venting. 13 p. 27 cm. (U. S. Forest service. Forest products laboratory, Madison, Wis.) (Press release.) [Manifolded.]

United States National advisory committee for aeronautics.
Ice formation on wings and other structural parts of aircraft. [4], 56 p. figs. plate. 26½ cm. (Preliminary report. March, 1928.)

SOLAR OBSERVATIONS

SOLAR AND SKY RADIATION MEASUREMENTS DURING JULY, 1928

By HERBERT H. KIMBALL, Solar Radiation Investigations

For a description of instruments and exposures and an account of the method of obtaining and reducing the measurements, the reader is referred to the REVIEW for January, 1924, **52**:42; January, 1925, **53**:29, and July, 1925, **53**:318.

Table 1 shows that solar radiation intensities were close to the normal values for July at all three stations.

Table 2 shows that the total solar radiation received on a horizontal surface directly from the sun and diffusely from the sky was above the July normal at Washington, slightly below at Madison, and decidedly below at Lincoln.

Skylight polarization measurements made at Washington on seven days give a mean of 46 per cent, with a maximum of 48 per cent on the 16th. At Madison measurements made on eight days give a mean of 61 per cent with a maximum of 72 per cent on the 14th. These are close to the corresponding average values for July at Madison and somewhat below at Washington.

TABLE 1.—*Solar radiation intensities during July, 1928*

[Graham-calories per minute per square centimeter of normal surface]

Washington, D. C.

Date	Sun's zenith distance										
	8 a.m.	78.7°	75.7°	70.7°	60.0°	0.0°	60.0°	70.7°	75.7°	78.7°	Noon
	75th mer. time	Air mass A. M.					Air mass P. M.				Local mean solar time
	e.	5.0	4.0	3.0	2.0	[1] 1.0	2.0	3.0	4.0	5.0	e.
	mm.	cal.	cal.	cal.	cal.	cal.	cal.	cal.	cal.	cal.	mm.
July 2	13.13				0.81	1.03					12.24
July 3	14.60	0.36	0.47	0.61	0.85	1.15					13.61
July 6	13.61	0.63	0.70	0.93	1.10	1.32					14.10
July 9	19.23			0.69	0.88	1.22					17.37
July 16	15.11	0.54	0.64	0.75	0.93	1.29					12.68
July 17	16.79		0.52	0.62	0.83	1.11					14.10
July 18	18.59				0.70						18.59
July 19	14.10			0.74	0.86						16.20
July 24	15.65	0.51	0.64	0.73	0.94						15.65
July 25	14.10				0.97	1.31					13.13
July 30	9.83				0.77						10.59
July 31	14.10			0.74	0.94						11.38
Means		0.51	0.61	0.73	0.88	1.29					
Departures		−0.05	−0.04	−0.03	−0.01	+0.03					

Madison, Wis.

Date	8 a.m.	5.0	4.0	3.0	2.0	1.0	2.0	3.0	4.0	5.0	Noon
July 3	9.14				1.17	1.35					9.83
July 6	6.76				1.03						7.87
July 7	7.29				1.05						9.47
July 11	6.27					1.30					10.59
July 23	10.21				1.14	1.32					10.97
July 24	10.21				0.93						10.59
July 25	11.38				0.92						15.65
July 28	8.81				1.19						12.24
Means					1.06	1.32					
Departures					+0.01	+0.04					

Lincoln, Nebr.

Date	8 a.m.	5.0	4.0	3.0	2.0	1.0	2.0	3.0	4.0	5.0	Noon
July 3	14.60				1.11	1.35					18.59
July 6	14.60						1.10	0.90	0.76		14.10
July 7	16.79			0.98							16.79
July 9	12.24		0.85	1.01	1.18	1.32					13.13
•July 13	13.61		0.74	0.88	1.13						10.97
July 26	15.65			0.83	1.08	1.31					13.13
July 27	11.38		0.66	0.78	0.95						8.81
Means			0.75	0.90	1.09	1.33	(1.10)	(0.90)	(0.76)		
Departures			−0.04	±0.00	±0.01	±0.00	+0.04	+0.02	+0.02		

[1] Extrapolated.

TABLE 2.—*Solar and sky radiation received on a horizontal surface*

[Gram-calories per square centimeter of horizontal surface]

Week beginning—	Average daily radiation						Average daily departure from normal		
	Washington	Madison	Lincoln	Chicago	New York	Twin Falls	Washington	Madison	Lincoln
1928	cal.	cal.	cal.	cal.	cal.	cal.	cal.	cal.	cal.
July 2	697	524	612	496	416	781	+206	−11	+29
July 9	449	542	531	436	310	682	−29	+9	−55
July 16	507	429	500	311	348	775	+37	−79	−69
July 23	510	542	482	408	439	711	+38	+50	−54
Excess or departure since first of year on July 29							+232	−697	−2,386

POSITIONS AND AREAS OF SUN SPOTS

[Communicated by Capt. C. S. Freeman, Superintendent U. S. Naval Observatory]

[Data furnished by Naval Observatory, in cooperation with Harvard, Yerkes, and Mount Wilson Observatories]

The differences of longitude are measured from central meridian, positive west. The north latitudes are plus. Areas are corrected for foreshortening and are expressed in millionths of sun's visible hemisphere. The total area, including spots and groups, is given for each day in the last column]

Date	Eastern standard civil time	Heliographic Diff. long.	Heliographic Longitude	Heliographic Latitude	Area Spot	Area Group	Total area for each day
1928	h. m.	°	°	°			
July 1 (Naval Observatory).	11 32	−72.0	106.7	−27.5		370	
		−24.0	154.7	+5.5		31	
		−20.0	158.7	+19.5		15	
		−17.0	161.7	+5.0	9		
		−6.0	172.7	+8.0	25		
		+17.5	196.2	+18.0		77	
		+22.5	201.2	+18.0		52	
		+32.0	210.7	+16.5	15		
		+37.0	215.7	−20.0		556	
		+40.0	218.7	−11.0		18	
		+44.5	223.2	−21.0	123		
		+46.5	225.2	+12.0	25		
		+54.0	232.7	−12.0	123		
		+71.0	249.7	+9.0	62		1,501
July 2 (Naval Observatory).	11 36	−65.0	100.4	−28.0		278	
		−58.5	106.9	−27.5	185		
		−56.0	109.4	−16.5	9		
		−11.0	154.4	+7.0		15	
		−3.0	162.4	+5.0		6	
		+8.5	173.9	+7.5	22		
		+32.5	197.9	+17.5		154	
		+49.0	214.4	−20.0		525	
		+53.5	218.9	−12.0		62	
		+59.0	224.4	−22.0	123		
		+60.0	225.4	+12.0	31		
		+67.5	232.9	−12.5	123		1,533
July 3 (Naval Observatory).	12 8	−51.5	100.4	−28.0		278	
		−47.0	104.9	−27.5	278		
		+22.0	173.9	+8.0	15		
		+24.5	176.4	+11.5	6		
		+38.5	190.4	−14.0		25	
		+41.0	192.9	−11.5		9	
		+45.0	196.9	+17.5		123	
		+62.0	213.9	−20.0		648	
		+66.0	217.9	−12.0		123	
		+70.5	222.4	−22.5	93		
		+82.0	233.9	−12.5	123		1,721
July 4 (Naval Observatory).	11 38	−40.5	98.4	−28.0		185	
		−34.0	104.9	−27.5		309	
		+40.5	179.4	+11.0		15	
		+55.0	193.9	−13.0	6		
		+57.0	195.9	+17.5		77	
		+72.0	210.9	−19.5	340		932
July 5 (Naval Observatory).	13 53	−86.0	38.4	+6.5	309		
		−26.5	97.9	−28.0		278	
		−19.5	104.9	−27.5		247	
		+50.0	174.7	−7.5	3		
		+52.5	176.9	+11.5		46	883
July 6 (Naval Observatory).	12 5	−78.0	34.2	−12.0	123		
		−72.5	39.7	+7.0		401	
		−16.0	96.2	−29.0		93	
		−12.5	99.7	−28.5		93	
		−8.0	104.2	−28.0		278	
		+67.5	179.7	+11.0		9	
		+68.5	180.7	−8.0	6		1,003
July 7 (Naval Observatory).	11 16	−68.0	31.4	−9.5		93	
		−64.0	35.4	−11.0	132		
		−62.5	36.9	+8.0		370	
		−58.0	41.4	+6.5	340		
		−3.0	96.4	−28.5		62	
		+0.5	99.9	−28.0		185	
		+4.5	103.9	−27.5	216		
		+62.5	161.9	+21.0	6		1,404
July 8 (Naval Observatory).	11 33	−74.0	12.0	+13.5	154		
		−53.0	33.0	−10.5		185	
		−51.0	35.0	+8.0		401	
		−45.0	41.0	+7.0	293		
		+12.5	98.5	−28.0		154	
		+18.0	104.0	−27.5		139	
		+68.5	154.5	+18.0	15		1,341
July 9 (Naval Observatory).	11 39	−60.5	12.2	+13.5	154		
		−40.0	32.7	−10.5		154	
		−38.0	34.7	+8.0		370	
		−31.0	41.7	+7.0	340		
		−18.0	54.7	−4.0	15		
		+26.5	99.2	−28.0		139	
		+30.5	103.2	−27.5		154	1,326
July 10 (Harvard)	9 10	−49.0	12.0	+15.0	270		
		−27.5	33.5	−10.0		103	
		−21.5	39.5	+8.0		896	
		+42.0	103.0	−27.5		210	1,479
July 11 (Naval Observatory).	11 58	−33.5	12.6	+13.5	154		
		−15.5	30.6	−4.5		22	
		−13.0	33.1	−11.0		93	
		−11.5	34.6	+8.0		370	
		−9.0	37.1	−10.5		31	
		−3.5	42.6	+7.0		340	
		+53.0	99.1	−28.0		93	
		+58.5	104.6	−27.0	123		1,226

POSITIONS AND AREAS OF SUN SPOTS—Continued

Date	Eastern standard civil time		Heliographic			Area		Total area for each day
			Diff. long.	Longitude	Latitude	Spot	Group	
1928—Continued	h.	m.	°	°	°			
July 12 (Naval Observatory).	11	48	−68.0	324.9	−20.0		309	
			−20.5	12.4	+13.0	170		
			−8.0	24.9	−10.5		31	
			−1.0	31.9	−5.0		62	
			−0.5	32.4	−11.0		93	
			+2.5	35.4	+8.0		370	
			+9.0	41.9	+7.0		278	
			+71.5	104.4	−27.0	123		1,436
July 13 (Naval Observatory).	12	6	−88.0	291.5	+9.5		216	
			−76.5	303.0	+9.0		247	
			−56.5	323.0	−21.0		216	
			−48.0	331.5	−18.5	278		
			−32.0	347.5	+7.0		25	
			−7.0	12.5	+13.0	154		
			+10.5	30.0	−5.0		37	
			+13.0	32.5	−11.0		31	
			+16.0	35.5	−5.5		15	
			+17.0	36.5	+8.0	370		
			+21.0	40.5	+7.0		108	
			+24.5	44.0	+6.0	154		1,851
July 14 (Naval Observatory).	11	2	−74.5	292.4	+10.0		247	
			−63.0	303.9	+9.0		370	
			−62.0	304.9	−26.5	6		
			−49.5	317.4	−15.5	6		
			−40.5	326.4	−20.0		278	
			−34.0	332.9	−18.5	324		
			−17.5	349.4	+6.0	6		
			+6.5	13.4	+13.0	139		
			+23.0	29.9	−5.5		25	
			+29.0	35.9	−6.0		31	
			+29.5	36.4	+8.0	340		
			+33.5	40.4	+7.5		62	
			+38.0	44.9	+5.5	123		1,957
July 15 (Naval Observatory).	11	29	−64.5	288.9	−10.0	12		
			−61.0	292.4	+10.0		370	
			−49.5	303.9	+9.5		340	
			−35.5	317.9	−15.0		31	
			−30.0	323.4	−21.0		370	
			−22.0	331.4	−18.0		432	
			+19.5	12.9	+13.0	154		
			+37.5	30.9	−4.5	31		
			+43.5	36.9	+8.0		432	
			+51.0	44.4	+5.0	170		2,342
July 16 (Naval Observatory).	11	33	−51.5	288.6	−11.0		62	
			−49.5	290.6	+5.0		62	
			−47.5	292.6	+8.5		247	
			−43.5	296.6	+13.5	6		
			−36.0	304.1	+8.0		216	
			−20.5	319.6	−15.0	9		
			−15.0	325.1	−21.0		463	
			−7.5	332.6	−18.0	370		
			+33.0	13.1	+13.0	123		
			+50.5	30.6	−4.5	15		
			+57.5	37.6	+8.0		401	
			+62.5	42.6	+5.0	154		2,128
July 17 (Naval Observatory).	11	37	−51.5	275.4	+18.0		15	
			−38.0	288.9	−10.5		46	
			−35.5	291.4	+5.0	77		
			−33.5	293.4	+9.0		231	
			−30.0	296.9	+12.5		93	
			−22.0	304.9	+8.5		231	
			−2.0	324.9	−21.0		463	
			+7.0	333.9	−18.0	432		
			+46.0	12.9	+13.0	123		
			+70.0	36.9	+8.0		370	
			+75.5	42.4	+5.0	154		2,235
July 18 (Naval Observatory).	11	39	−39.5	274.1	+18.0		77	
			−28.5	285.1	+8.5	6		
			−23.0	290.6	−10.5		31	
			−21.0	292.6	+5.5	77		
			−20.0	293.6	+8.5		216	
			−17.0	296.6	+12.5		31	
			−9.5	304.1	+9.0		201	
			+11.5	325.1	−21.0		617	
			+20.0	333.6	−18.0	370		
			+27.5	341.1	+2.5		37	
			+59.0	12.6	+13.0	139		
			+82.5	36.1	+8.0		300	2,111
July 19 (Naval Observatory).	11	44	−27.0	273.4	+17.5		93	
			−13.0	287.4	+7.0		46	
			−11.5	288.9	−10.5		9	
			−9.0	291.4	+5.5	56		
			−7.5	292.9	+8.5		247	
			−6.0	294.4	+12.5		62	
			+4.0	304.4	+9.0		185	
			+23.5	323.9	−21.0		432	
			+32.5	332.9	−18.0	370		
			+39.0	339.4	+2.0		37	
			+49.5	349.9	+7.5		31	
			+71.5	11.9	+13.0	139		1,707

POSITIONS AND AREAS OF SUN SPOTS—Continued

Date	Eastern standard civil time		Heliographic			Area		Total area for each day
			Diff. long.	Longitude	Latitude	Spot	Group	
1928—Continued	h.	m.	°	°	°			
July 20 (Naval Observatory).	12	3	−81.0	206.0	+13.0		154	
			−16.0	271.0	+18.0		31	
			−10.5	276.5	+17.0		62	
			−1.0	286.0	+8.0		31	
			+3.5	290.5	+5.0		62	
			+7.5	294.5	+9.0		185	
			+8.0	295.0	+13.0		77	
			+18.0	305.0	+9.0		185	
			+37.0	324.0	−21.0		340	
			+47.0	334.0	−18.0	370		
			+53.5	340.5	+2.5		31	
			+67.0	354.0	+7.5		9	1,537
July 21 (Harvard)	9	39	−70.0	205.0	+14.5	270		
			−65.0	210.0	−19.5	38		
			+20.5	295.5	+10.0		493	
			+54.0	329.0	−19.0		754	1,555
July 22 (Naval Observatory).	13	2	−59.5	200.5	+12.5		31	
			−53.5	206.5	+13.0		154	
			−49.5	210.5	−20.0	22		
			+20.0	280.0	−8.0		15	
			+22.0	282.0	+5.0	9		
			+32.5	292.5	+13.5		40	
			+34.0	294.0	+9.0		185	
			+44.5	304.5	+9.5	108		
			+62.0	322.0	−22.5		154	
			+66.5	326.5	−20.0		46	
			+75.0	335.0	−18.0		370	1,134
July 24 (Naval Observatory).	12	8	−68.5	165.5	−11.0	31		
			−65.0	169.0	+5.5		154	
			−38.0	196.0	+17.5		9	
			−31.0	203.0	+14.0		93	
			−28.0	206.0	+13.0	108		
			−23.5	210.5	−19.5		6	
			+58.0	292.0	−20.0		201	
			+59.5	293.5	+9.0		154	
			+60.5	294.5	+9.5	123		879
July 25 (Naval Observatory).	11	54	−80.0	140.9	−22.5		247	
			−70.0	150.9	−21.0	108		
			−58.5	162.4	−17.0		15	
			−53.5	167.4	+5.5		93	
			−23.0	197.9	+17.0		15	
			−17.5	203.4	+14.0		62	
			−15.0	205.9	+13.0	93		
			+49.5	270.4	+15.0	25		
			+71.0	291.9	−20.0		201	
			+72.5	293.4	+9.0		123	
			+85.0	305.9	+9.5	123		1,105
July 26 (Naval Observatory).	11	55	−67.5	140.1	+14.5		46	
			−64.0	143.6	−22.5		340	
			−58.0	149.6	−20.5	108		
			−39.5	168.1	+5.5		77	
			−10.0	197.6	+17.0		6	
			−4.5	203.1	+14.0		46	
			−2.0	205.6	+13.0	93		
			+62.5	270.1	+15.0	139		855
July 27 (Mount Wilson)	10	0	−56.5	138.9	+14.5		64	
			−50.0	145.4	−22.0		482	
			−26.0	169.4	+5.0		44	
			+11.0	206.4	+14.0		131	
			+77.0	272.4	+16.5		166	887
July 28 (Naval Observatory).	11	11	−83.5	98.1	−15.0	123		
			−83.0	98.6	+7.0	247		
			−44.5	137.1	+13.5		108	
			−40.0	141.6	+12.5	108		
			−39.0	142.6	−22.0		231	
			−32.0	149.6	−20.5	77		
			−16.0	165.6	+5.5		31	
			−11.0	170.6	+5.5		25	
			+24.0	205.6	+13.0	108		1,058
July 29 (Naval Observatory).	11	33	−70.5	97.7	+7.5		185	
			−66.0	102.2	−25.0	46		
			−63.5	104.7	−15.5	62		
			−30.0	138.2	+14.0		586	
			−27.5	140.7	−21.0		185	
			−18.0	150.2	−20.0	62		
			+1.5	169.7	+6.0		93	
			+38.0	206.2	+13.5	93		1,312
July 30 (Naval Observatory).	11	38	−57.0	97.9	+7.5		185	
			−56.0	98.9	−14.5	6		
			−54.0	100.9	−25.0	62		
			−49.5	105.4	−15.5	46		
			−48.0	106.9	+13.0		31	
			−15.5	139.4	+13.5		617	
			−12.5	142.4	−21.0		93	
			−4.0	150.9	−20.0	46		
			+12.5	167.4	+6.0		62	
			+19.0	173.9	+7.0		46	
			+51.5	206.4	+13.5	93		1,287

POSITIONS AND AREAS OF SUN SPOTS—Continued

Date	Eastern standard civil time	Heliographic			Area		Total area for each day
		Diff. long.	Longitude	Latitude	Spot	Group	
1928—Continued	h. m.	°	°	°			
July 31 (Naval Observatory).	11 42	−43.5	98.1	+7.5		170	
		−43.0	98.6	−14.5	3		
		−42.5	99.1	−25.0	31		
		−35.5	106.1	−15.5	46		
		−34.5	107.1	+13.0		15	
		−6.0	135.6	+14.0		370	
		+1.0	142.6	+13.0	370		
		+1.5	143.1	−20.0		31	
		+9.5	151.1	−20.0		37	
		+25.5	167.1	+7.0		37	
		+30.5	172.1	+7.0		62	
		+65.0	206.6	+13.5	108		1,280
Mean daily area for July							1,434

PROVISIONAL SUN-SPOT RELATIVE NUMBERS FOR JULY, 1928

[Data furnished by Prof. A. Wolfer, University of Zurich, Switzerland]

July	Relative numbers	July	Relative numbers	July	Relative numbers
1	125	11	69	21	127
2	135	12	127	22	114
3	133	13	131	23	77
4	88	14	132	24	54
5	59	15	149	25	60
6	52	16	145	26	66
7		17	133	27	66
8	97	18	118	28	76
9	91	19	124	29	98
10	85	20	129	30	97
				31	105

Number of observations, 30; mean, 101.2.

AEROLOGICAL OBSERVATIONS

By W. R. STEVENS

Free-air temperatures for July were slightly below normal at Ellendale and Groesbeck, but were slightly above at the other kite stations.

There were no important departures from the normal relative humidity at levels where observations were frequent enough to give reliable monthly means.

Vapor pressures were quite generally above normal, except for the higher levels at Ellendale, Groesbeck, and Royal Center.

Wind resultants as determined from pilot balloons were almost entirely of southerly component near the surface, but at the majority of the stations shifted gradually to northerly component with altitude. The base of the antitrades was reached on a few occasions at San Juan, the altitude ranging between 5,000 and 9,000 meters. Easterly winds at high levels were observed at a number of stations in the Northwest from the 19th to the 25th. As is usual in conditions of this kind, there was a lack of cyclonic activity over that section. A double-theodolite pilot-balloon observation at Ellendale on the afternoon of the 12th showed fairly strong convectional currents from the surface to the point where it entered cumulus clouds at 1,400 meters. The highest vertical velocity observed was 3.2 m. p. s. between 750 meters and 1,100 meters. Another observation at the same station on the afternoon of the 27th showed an average vertical velocity of 2 m. p. s. from the surface to 1,715 meters where the balloon entered strato-cumulus clouds. The maximum vertical velocity was 2.9 m. p. s. between 1,250 and 1,600 meters.

The month was quite generally unfavorable for daily kite work. Flights at most stations were necessarily limited as to altitude and frequency because of light winds and the frequent occurrence of thunderstorms.

TABLE 1.—*Free-air temperatures, relative humidities and vapor pressures during July, 1928*

TEMPERATURE (°C.)

Altitude m. s. l.	Broken Arrow, Okla. (233 meters)		Due West, S. C. (217 meters)		Ellendale, N. Dak. (444 meters)		Groesbeck, Tex. (141 meters)		Royal Center, Ind. (225 meters)		Washington, D. C. [1] (7 meters)	
	Mean	Departure from normal	Mean	Departure from normal	Mean	Departure from normal	Mean	Departure from normal	Mean	Departure from normal	Mean	Departure from normal
Meters												
Surface	27.4	+0.8	26.6	−0.5	21.3	+0.3	25.1	−1.5	25.1	+0.2	29.1	+4.3
250	27.2	+0.7	26.2	−0.5			24.4	−1.3	24.9	+0.3	25.9	+3.0
500	25.2	+0.3	23.8	−0.5	20.7	+0.1	23.2	−0.7	22.6	+0.5	24.2	+2.7
750	23.9	+0.4	22.7	+0.1	18.8	−0.4	22.6	−0.2	20.3	0.0	23.0	+2.6
1,000	23.3	+1.2	21.2	+0.3	17.3	−0.7	21.7	0.0	18.3	−0.2	21.3	+2.3
1,250	22.4	+1.8	19.5	+0.3	15.9	−1.0	20.5	0.0	16.5	−0.4	19.3	+1.8
1,500	21.0	+1.9	17.9	+0.3	14.7	−1.0	19.2	0.0	14.9	−0.5	17.3	+1.3
2,000	18.2	+2.1	14.8	+0.5	12.1	−0.9	16.4	−0.1	11.9	−0.6	13.3	+0.3
2,500	15.2	+2.2	11.7	+0.5	9.2	−0.9	13.1	−0.5	8.5	−1.3	10.4	+0.2
3,000	12.0	+2.2	8.8	+0.5	6.1	−1.1	10.0	−0.7	7.8	+0.7	8.8	+1.2
3,500	9.5	+2.6	5.9	+0.6	3.1	−1.2	6.8	−0.9	5.2	+0.9		
4,000	7.0	+3.1			0.4	−1.2	3.8	−0.9	2.5	+1.0		
4,500	4.3	+2.9			−2.6	−1.7	0.7	−2.1				

[1] Naval air station.

TABLE 1.—*Free-air temperatures, relative humidities and vapor pressures during July, 1928*—Continued

RELATIVE HUMIDITY (%)

Altitude m. s. l.	Broken Arrow, Okla. (233 meters)		Due West, S. C. (217 meters)		Ellendale, N. Dak. (444 meters)		Groesbeck, Tex. (141 meters)		Royal Center, Ind. (225 meters)		Washington, D. C. (7 meters)	
	Mean	Departure from normal	Mean	Departure from normal	Mean	Departure from normal	Mean	Departure from normal	Mean	Departure from normal	Mean	Departure from normal
Meters												
Surface	73	+4	72	+6	72	+3	84	+9	66	+4	67	−5
250	73	+4	73	+7			85	+9	66	+4	70	−3
500	74	+8	76	+8	72	+4	83	+6	65	+1	65	−4
750	71	+7	73	+4	70	+6	72	0	69	+3	61	−5
1,000	63	0	72	+2	70	+8	63	−4	71	+3	61	−4
1,250	57	−6	73	+2	70	+10	59	−5	72	+4	64	−2
1,500	57	−5	73	+2	68	+10	55	−7	68	+1	66	−1
2,000	53	−6	73	+2	59	+4	51	−8	61	−2	70	+2
2,500	51	−7	74	+4	57	+4	51	−7	60	+3	62	−4
3,000	55	−3	68	0	52	+1	46	−11	32	−19	35	−25
3,500	55	−2	69	+1	49	−1	40	−17	30	−18		
4,000	56	−1			41	−9	36	−24	28	−15		
4,500	60	+7			40	−10	36	−5				

VAPOR PRESSURE (mb.)

Altitude m. s. l.	Broken Arrow Mean	Departure	Due West Mean	Departure	Ellendale Mean	Departure	Groesbeck Mean	Departure	Royal Center Mean	Departure	Washington Mean	Departure
Surface	26.39	+2.36	24.94	+1.77	18.23	+1.12	26.51	+0.88	21.04	+1.55	27.05	+4.20
250	26.17	+2.35	24.68	+1.84			25.71	+0.96	20.75	+1.54	23.41	+2.84
500	23.63	+2.68	22.35	+1.97	17.66	+1.12	23.24	+0.76	18.01	+1.00	19.63	+1.79
750	21.13	+2.33	19.98	+1.30	15.34	+0.99	19.27	−0.37	16.68	+1.10	17.26	+1.26
1,000	18.05	+0.90	17.99	+0.76	13.91	+1.06	15.93	−1.07	15.16	+0.79	15.63	+1.15
1,250	15.33	−0.10	16.45	+0.60	12.64	+1.11	13.73	−1.28	13.45	+0.48	14.59	+1.31
1,500	13.91	+0.04	14.88	+0.56	11.22	+0.92	11.87	−1.60	11.38	−0.17	13.36	+1.08
2,000	10.76	−0.23	12.26	+0.58	8.21	−0.08	9.21	−1.74	8.11	−0.74	11.39	+1.20
2,500	8.54	−0.29	10.17	+0.79	6.41	−0.31	7.06	−1.35	5.90	−0.59	8.72	+0.50
3,000	7.51	+0.30	7.83	+0.26	4.87	−0.54	6.01	−1.58	3.06	−1.81	4.08	−1.25
3,500	6.35	+0.42	6.60	+0.38	3.94	−0.56	4.75	−1.06	2.06	−1.75		
4,000	5.88	+1.03			3.02	−0.70	4.04	−1.70	1.75	−1.07		
4,500	5.23	+1.43			2.63	−0.54	3.86	−0.22				

TABLE 2.—*Free-air resultant winds (m. p. s.) during July, 1928*

Altitude m. s. l.	Broken Arrow, Okla. (233 meters)				Due West, S. C. (217 meters)				Ellendale, N. Dak. (444 meters)				Groesbeck, Tex. (141 meters)				Royal Center, Ind. (225 meters)				Washington, D. C. (34 meters)			
	Mean		Normal		Mean		Normal		Mean		Normal		Mean		Normal		Mean		Normal		Mean		Normal	
	Dir.	Vel.	Dir.	Vel.	Dir.	Vel.	Dir.	Vel.	Dir.	Vel.	Dir.	Vel.	Dir.	Vel.	Dir.	Vel.	Dir.	Vel.	Dir.	Vel.	Dir.	Vel.	Dir.	Vel.
Meters	°		°		°		°		°		°		°		°		°		°		°		°	
Surface	S. 15 W.	5.4	S. 4 W.	3.2	S. 80 W.	2.3	S. 63 W.	1.1	N. 43 W.	0.8	N. 18 W.	0.3	S. 11 W.	3.7	S. 17 W.	3.6	S. 73 W.	3.0	S. 81 W.	1.5	S. 88 W.	0.9	N. 42 W.	0.5
250	S. 18 W.	5.6	S. 3 W.	3.3	S. 83 W.	2.5	S. 65 W.	1.2					S. 15 W.	5.5	S. 19 W.	4.4	S. 71 W.	3.3	S. 80 W.	1.7	N. 76 W.	3.0	N. 62 W.	1.5
500	S. 17 W.	6.9	S. 12 W.	4.8	W.	3.7	S. 74 W.	1.9	N. 47 W.	0.6	N. 45 W.	0.1	S. 25 W.	7.8	S. 26 W.	6.2	S. 68 W.	4.9	S. 72 W.	3.1	N. 60 W.	4.4	N. 57 W.	2.2
750	S. 22 W.	7.8	S. 21 W.	5.2	S. 87 W.	4.0	S. 82 W.	2.2	S. 82 W.	0.7	S. 35 W.	0.9	S. 24 W.	8.1	S. 27 W.	6.4	S. 75 W.	5.7	S. 74 W.	3.9	N. 54 W.	4.4	N. 47 W.	2.7
1,000	S. 32 W.	8.0	S. 28 W.	5.1	N. 73 W.	3.7	S. 88 W.	2.4	S. 84 W.	0.9	S. 57 W.	1.3	S. 18 W.	8.1	S. 27 W.	6.1	S. 76 W.	6.8	S. 82 W.	4.5	N. 52 W.	4.8	N. 52 W.	3.0
1,250	S. 39 W.	7.6	S. 33 W.	4.8	N. 86 W.	4.8	S. 88 W.	2.8	W.	1.4	S. 70 W.	1.8	S. 14 W.	7.1	S. 26 W.	5.6	S. 77 W.	6.8	S. 84 W.	5.3				
1,500	S. 44 W.	7.0	S. 39 W.	4.5	N. 68 W.	4.6	S. 88 W.	3.7	S. 85 W.	2.5	S. 79 W.	2.6	S. 9 W.	6.5	S. 25 W.	5.1	S. 76 W.	7.8	S. 87 W.	6.2	N. 63 W.	4.9	N. 56 W.	3.9
2,000	S. 46 W.	6.4	S. 43 W.	3.8	N. 73 W.	4.2	N. 85 W.	5.2	N. 83 W.	4.2	N. 89 W.	4.0	S. 6 W.	5.0	S. 24 W.	4.2	S. 72 W.	8.4	S. 88 W.	7.4	N. 74 W.	5.6	N. 65 W.	4.7
2,500	S. 50 W.	5.1	S. 55 W.	3.8	N. 79 W.	5.9	N. 84 W.	6.4	N. 70 W.	5.7	N. 81 W.	5.7	S. 5 W.	4.5	S. 21 W.	4.0	S. 86 W.	9.1	N. 88 W.	9.7	N. 72 W.	6.0	N. 69 W.	5.8
3,000	S. 37 W.	4.1	S. 59 W.	4.1	N. 80 W.	7.2	N. 88 W.	7.9	N. 70 W.	7.8	N. 80 W.	7.5	S. 3 W.	3.8	S. 19 W.	4.1	N. 87 W.	10.3	N. 89 W.	11.2	N. 70 W.	7.8	N. 72 W.	7.3
3,500	S. 33 W.	4.8	S. 76 W.	4.4	N. 67 W.	8.0	N. 83 W.	8.3	N. 78 W.	10.0	N. 75 W.	10.1	S. 26 E.	6.5	S. 9 W.	3.2	S. 80 W.	11.5	S. 88 W.	10.8	N. 81 W.	8.1	N. 78 W.	7.9
4,000	S. 32 W.	5.5	S. 81 W.	5.3					N. 69 W.	15.7	N. 69 W.	11.5	S. 56 E.	5.4	S. 52 W.	0.9	S. 58 W.	11.2	N. 74 W.	9.7	N. 76 W.	6.8	N. 70 W.	8.2
4,500	S. 28 W.	5.9	S. 76 W.	7.2					N. 77 W.	18.3	N. 68 W.	13.7	E.	8.0	N. 25 E.	1.7	S. 67 W.	13.0	N. 62 W.	8.9	N. 70 W.	7.6	N. 82 W.	8.2
5,000													E.	7.0	N. 59 E.	3.5					S. 84 W.	7.2	N. 85 W.	8.8

WEATHER IN THE UNITED STATES

THE WEATHER ELEMENTS

By P. C. DAY

GENERAL CONDITIONS

July, 1928, was notable mainly for the closeness by which the various weather elements approached the conditions expected in a normal midsummer month. A short period of unusual warmth occurred near the end of the month in portions of the far Northwest, but otherwise temperatures were moderate. Thunderstorms or other violent electrical disturbances were not unduly frequent as a rule, and damage by wind and hail, while considerable over limited areas, was, on the whole, less than usually occurs in July.

PRESSURE AND WINDS

A survey of the daily weather maps for July, 1928, shows few cyclonic areas of importance, and precipitation was mostly of the usual thunderstorm type, heavy in some instances, but these were confined usually to widely separated areas.

The most important cyclone of the first decade was observed on the morning of the 4th over the middle Plains, whence it moved to the vicinity of the lower Lakes during the following 24 hours, attended by considerable precipitation over the region traversed. By the morning of the 6th the low pressure had apparently moved toward the middle Atlantic coast and merged with a secondary depression that had developed during the preceding night over that region. The precipitation attending this depression was rather heavy over most of the coast districts from Pennsylvania to southern New England. During the 9th and 10th considerable rain fell over an extensive area from the Great Lakes southeastward to Florida, and to the eastward on the 10th and 11th, the falls being excessive in a few localities, Greenville, S. C., having about 4 inches in less than six hours.

By the morning of the 13th low pressure had developed over the southern drainage area of the Ohio, and widespread rains had fallen over most districts from the Mississippi River eastward. During the following 24 hours the barometric depression had moved to Lake Ontario and rain had spread into all eastern districts, with heavy falls over portions of the lower Lakes, Ohio Valley, and Middle Atlantic States.

About the 17th and 18th considerable precipitation occurred over the Southeastern States, though there was no appreciable barometric depression at that time over the region of important precipitation. About the same time there was considerable precipitation over the northern Rocky Mountains and thence eastward to Lake Superior, the precipitation continuing over the western districts during the 19th and extending into the eastern lake region and North Atlantic States on the 20th and 21st.

Some local heavy rains occurred on the 21st and 22d from the middle and northern Plains eastward, the general barometric depression assuming a cyclonic form over southern New England by the morning of the 23d, more or less rain continuing over that region during the following day.

From the 26th to 28th a fairly well marked cyclone moved from western Lake Superior to the St. Lawrence Valley, attended by rather general precipitation over the Northern States from Minnesota to New England. At the same time local precipitation set in over the Gulf States, where some good rains occurred on the 26th and 27th.

Local precipitation occurred over the far Northwest during the first week, but otherwise there was little or no precipitation west of the Rocky Mountains.

Anticyclones were weak and exerted little important influence in modifying the weather over extensive areas or for lengthy periods. In fact, temperature changes were unusually small in all parts of the month and throughout nearly the entire country.

The mean pressure of the month did not depart greatly from the normal, and the pressure variations over the different parts were not sufficiently pronounced to cause important variations from the normal wind movement.

Local storms occurred, as is usual in midsummer, over the eastern two-thirds of the country, and they were rather frequent in portions of Nebraska, Iowa, and other near-by areas. No extensive loss of life was reported from tornadoes and damage from such storms was comparatively small. Full details concerning damaging winds, hail, and other storms appear at the end of this section.

TEMPERATURE

As stated elsewhere, there were no important variations in temperature as compared with the normal condition, though an unusually heated period occurred over portions of the far Northwest during the last decade. This was most severely felt over the eastern portions of Washington and Oregon, and in Idaho, where from about the 21st to

29th the temperatures were continuously high, reaching a maximum of 118° at some points, and exceeding by several degrees the highest temperatures ever previously recorded at a number of points.

The first 10 days were mainly warm and moderately dry, affording a welcome change from the cool, rainy conditions that had existed for practically the entire month of June over much of the eastern two-thirds of the country.

The week ending July 17 was mainly warmer than normal over the more western districts, but moderately cool over the central valleys and to the eastward, save over the extreme Northeastern States. Rainfall was well distributed and the week as a whole was unusually favorable for midsummer. The week ending July 24 was moderately warmer than normal in the central valleys and eastern districts and mainly cooler than normal in the mountain and plateau regions, but decidedly warm during the last few days in the far Northwest.

The last week was moderately cool over most districts from the Rocky Mountains eastward, save along the immediate Gulf and South Atlantic coasts, where it was slightly warmer than normal. West of the Rocky Mountains the week, as a whole, was mainly unusually warm, particularly in the far Northwestern States, where the weekly averages ranged from 6° to 12° above the normal, and the period of unusual continued heat was in numerous instances the longest of record.

The fairly frequent changes in temperature, though not of large magnitude, and the absence of continued excessive heat except in small areas, caused the month to be rated as physically comfortable in nearly all parts.

The average temperature for the month was close to normal in practically all portions, the only region having an excess of more than 3° being the northern portion of the plateau, where the positive departures ranged up to as much as 5°.

The highest temperatures were widely scattered as to dates, but they were particularly high on the 25th and 26th in the plateau region. The highest temperature reported was 120° in southern California, and temperatures were above 95° at some time during the month locally in all the States.

Minimum temperatures were below freezing at exposed points in all the western Mountain States; the lowest, 20°, was recorded in the high mountains of Colorado.

PRECIPITATION

As in the case of temperature, the monthly precipitation was close to the normal in practically all districts, though a few stations in the northern Great Plains had the greatest July amounts of record. The falls were mainly well distributed through the month, and at the close no important agricultural areas were suffering from a serious lack of soil moisture.

RELATIVE HUMIDITY AND CLOUDINESS

The relative amount of moisture, like the other principal weather elements, was mainly close to the normal, principally slightly above, except in the Missouri Valley, where it was materially higher than normal. Over the Southwest a moderate deficiency was fairly general, and there were slight deficiencies in the Middle Atlantic States and locally in Texas.

Much clear weather prevailed in nearly all parts of the country, particularly in the central valleys and to the westward, and similar conditions prevailed in the lake region and Atlantic Coast States. Considerable cloudy weather prevailed in the Southeastern States and portions of Florida and extreme northeastern New England

SEVERE LOCAL STORMS, JULY, 1928

The table herewith contains such data as have been received concerning severe local storms that occurred during the month. A more complete statement will appear in the Annual Report of the Chief of Bureau.

Place	Date	Time	Width of path, yards[1]	Loss of life	Value of property destroyed	Character of storm	Remarks	Authority
Miller, S. Dak.	1	8-9 p. m.	330		$20,000	Tornado	Farm buildings destroyed	Official, U. S. Weather Bureau.
Huron, S. Dak.	1	9 p. m.	3 mi.		10,000	Wind	Hangar and airplane destroyed; many buildings damaged.	Do.
Anoka, Minn. (north of)	1	Midnight			100,000	Tornado	Extensive property damage reported	Do.
Brookings, S. Dak.	1				10,000	Wind	Hangar and 1 airplane wrecked; some farm buildings damaged.	Do.
Minneota, Minn.	1				60,000	Tornado	Much damage to property	Do.
Wisconsin (west-central and central).	2	12:30-2:30 a. m.			400,300	Severe squall; probably 2 small tornadoes.	Damage to barns, silos, stock, overhead wires, and crops in 7 counties.	Do.
Howard, Mitchell, and Winneshiek Counties, Iowa.	2					Hail	Damage chiefly to crops	Do.
Minatare, Nebr.	3	3 p. m.	3,520		5,000	do	Crops and gardens injured in places; path 3 miles.	Do.
Shelby County, Iowa	3	9 p. m.				Tornado	Crops and buildings damaged	Do.
Crawford County, Iowa	3	P. m.			17,000	do	Character of damage not reported	Do.
Iowa	3	do				Wind and hail	Considerable damage to crops and buildings over entire State.	Do.
Stark and Peoria Counties, Ill.	3	11 p. m.	12 mi.		20,000	Wind	Buildings damaged	Do.
Stratton, Nebr.	3	P. m.	3 mi.		25,000	Hail	Crops damaged 10 to 90 per cent in places over path 5 miles long.	Do.
Nebraska (central)	3-4		100 mi.		11,000	Wind	Small grain lodged; a few small buildings demolished, others damaged; path 100 miles.	Do.
College View, Nebr.	4	1 a. m.			5,000	do	A business block and a residence unroofed; 2 garages demolished; trees uprooted.	Do.
Iowa	4	A. m.				Wind and hail	Heavy damage to crops and other property over entire state.	Do.
Wayne and Lenoir Counties, N. C.	4	5 p. m.			17,000	Hail	Considerable crop damage	Do.
Indianapolis, Ind., and vicinity.	4					Wind and rain	Trees and wire systems damaged; light and car service interrupted.	Do.
Elvaston, Bentley, Plymouth, and Colmar, Ill.	4				6,000	Wind	Property damaged over path 30 miles long	Do.
Lincoln, Ill. (near)	4		1,320		6,000	do	Crops flattened	Do.
Massachusetts (east-central).	4			3		Gales	Much damage to property; a number of boats capsized; traffic jammed; light and telephone service crippled; several persons injured.	Boston Herald (Mass.).

[1] "Mi." signifies miles instead of yards.

Place	Date	Time	Width of path, yards [1]	Loss of life	Value of property destroyed	Character of storm	Remarks	Authority
Pittsburgh, Pa., and vicinity.	4					Wind, rain and electricity.	400 automobiles wrecked by landslides; 2,000 persons marooned by floods; small buildings damaged by lightning.	Official, U. S. Weather Bureau.
Washington County, Md. (northern).	4					Wind	Trees uprooted; telephone and electric wires broken.	Do.
Ramsey County, N. Dak.	5				$25,000	Several small tornadoes.	Farm buildings and crops damaged	Do.
Richville, N. Y.	5				25,000	Thundersquall	Nearly all buildings damaged; trees and telephone lines blown down.	Do.
Evansville, Ind., and vicinity.	6	A. m.				Electrical, wind and rain.	Basements flooded; power lines broken; crops laid flat.	Do.
Scotts Bluff County, Nebr. (northern).	6	3 p. m.	880		20,000	Hail	Crops badly injured	Do.
Chattanooga, Tenn.	7	A. m.				Wind and rain	Damage chiefly to wires and poles; crops and gardens injured.	Do.
Scott County, Kans.	7	7-9 p. m.	6-12 mi.		60,000	Hail	Damage chiefly to growing crops; path 30 miles.	Do.
Iowa	7	P. m.				Wind and hail	Crops and buildings considerably damaged in 13 counties.	Do.
Nashville, Tenn.	7				2,000	Wind	Windows broken; telephone and electric service crippled.	Do.
Portage, Langlade, and Oconto Counties, Wis.	8	4-5 p. m.			13,500	Severe squall	Chief damage to farm property	Do.
Eads, Colo.	8	6:30 p. m.	1,760			Hail	Crops and gardens damaged	Do.
Iowa	8	P. m.				Wind and hail	Considerable damage to crops and buildings in 8 counties.	Do.
Peru, N. Y.	9	2-5 p. m.	3 mi.		15,000	Hail	Much damage to apple crop	Do.
Phelps, Gosper, and Furnas Counties, Nebr.	9	3 p. m.	20 mi.			do.	Crops damaged 15 per cent to total in places over path 20 miles long.	Do.
Buffalo County, Nebr. (southern).	9	4 p. m.	3 mi.		75,000	do.	Crops severely damaged	Do.
Colfax County, Nebr. (southern).	9	4:30 p. m.	3,520		60,000	do.	Heavy crop damage in places; path 10 miles.	Do.
Beaver City, Nebr. (near)	9	do.	5 mi.		10,000	do.	Severe damage to crops in small areas	Do.
Harlan and Furnas Counties, Nebr.	9	5-6 p. m.	8 mi.		100,000	do.	Crop damaged 25 per cent to total	Do.
Wayne and Dixon Counties, Nebr.	9	6:45 p. m.	1,760			do.	Crops damaged 5 to 50 per cent over path 8 miles long.	Do.
Iowa	9	P. m.				Hail and wind	Crops injured; many windows broken; livestock hurt in 6 counties.	Do.
Brunswick, Mo.	10	6:30 p. m.				Wind	Buildings, trees, and crops damaged	Do.
Benton, Appanoose, and Guthrie Counties, Iowa.	10					Wind and hail	Damage mainly to crops	Do.
Crawford and Bourbon Counties, Kans.	11	12:30 a. m.	25 mi.		10,000	Thunderstorm	Buildings damaged; wire services crippled; path 40 miles.	Do.
Rushville, Nebr.	11	4 p. m.	4 mi.		100,000	Hail	Crops beaten; buildings damaged; poultry killed; livestock injured; path 30 miles.	Do.
Scotts Bluff County, Nebr.	11	5 p. m.	3,520		100,000	do.	Extensive damage to crops; path 6 miles	Do.
Frederick, Md.	11	P. m.			34,000	Wind and hail	A number of buildings partly unroofed; windows blown in; trees uprooted; gardens damaged.	Do.
Dundee, N. Y. (near)	11					Thunderstorm and hail.	Trees and telephone lines considerably damaged; crops and orchards injured.	Do.
Franklin County, Pa.	11					Hail	Heavy crop damage over narrow path	Do.
Nevada and Lamonte, Mo.	11					Wind and hail	Much damage to crops, buildings, greenhouses, and trees.	Do.
Washington County, Md. (northeastern).	11				50,000	Hail	Orchards and raspberry plantations damaged; small animals killed; crops injured.	Do.
Spooner, Wis. (near)	12	1 p. m.	10 mi.		10,000	do.	Crops damaged	Do.
La Crosse and Monroe Counties, Wis.	12	2:30 p. m.	3 mi.		50,000	Hail	Crop loss heavy	Do.
Roy, N. Mex. (near)	12	3 p. m.				do.	Wheat crop damaged about 50 per cent	Do.
Iowa	12	P. m.				Wind and hail	Damage chiefly to crops in 14 counties	Do.
Arvada, Wyo. (near)	17	do.				Hail	Crops laid waste; livestock killed or injured	Sheridan Post Enterprise (Wyo.).
Clarkelen, Wyo. (north of).	17					do.	All crops in 4 sections destroyed; small animals killed.	Official, U. S. Weather Bureau.
Clarkelen, Wyo. (12 miles north of).	18		7 mi.			do.	Crops on 45 farms ruined; hogs and chickens killed.	Do.
Monroe County, Iowa	19	6 a. m.			1,000	Tornado	Buildings damaged	Do.
Aurora, Ill.	19	11:30 a. m.				Wind, electrical, and hail.	Trees and buildings damaged; car and wire services interrupted; crops flattened.	Do.
Iowa	19	P. m.				Wind, hail, and floods.	Much injury to crops; some damage to buildings in 6 counties.	Do.
Do.	20	A. m.				do.	Extensive crop injury; some damage to buildings in 5 counties.	Do.
Blunt to Lane, S. Dak.	20	5-7:30 p. m.	3 mi.		145,000	Hail and wind	Extensive property damage	Do.
Aspermont, Tex. (near)	20	6 p. m.	400			Probably tornado.	4 small buildings demolished; considerable crop damage; 1 person injured.	Do.
Gannvalley to Mount Vernon, S. Dak.	20	6:30 p. m.	4 mi.		133,000	Hail and wind	Crops destroyed; buildings damaged.	
Canon City, Colo.	20	P. m.			100,000	Hail	Orchards and crops ruined	Do.
Mifflintown, Pa. (near)	20	do.				Small tornado	A barn demolished; many trees uprooted	Do.
Greentown, Ind.	20					Tornadic wind	Corn and oats damaged	Do.
Ross, Wyo. (near)	20					Hail	80 acres of oats shattered; other fields partial to total loss.	Do.
Fort Wayne, Ind.	21				75,000	Severe thunderstorm.	Severe damage to buildings	Do.
Kokomo, Ind. (near)	21				50,000	do.	Heavy crop loss	Do.
Carlisle, Pa., and vicinity	22	2:30 p. m.	1,000		25,000	Hail and wind	Damage confined to roofs; windows, etc.; some crop injury.	Do.
Morgantown, Md. (near)	22	5:30 p. m.		1	10,000	Probably tornado.	Several small buildings demolished; 1 person injured.	Do.
Steuben County, N. Y.	23	4:30 p. m.				Hail and thunderstorm.	Many vineyards ruined; crops, highways, and cottages damaged.	Do.
Scotts Bluff County, Nebr.	24	3 p. m.	6 mi.		50,000	Hail	Damage chiefly to crops	Do.
Cedarvale, N. Mex.	24	3-4 p. m.	3,520			do.	Crops almost a total loss	Do.
Iowa	26	P. m.				Hail and wind	Crops damaged considerably in 17 counties	Do.
Minatare, Nebr.	27	2 a. m.	7 mi.		19,700	Hail	Beets, gardens, and small grains damaged	Do.
Ault, Colo.	28		1,760			do.	Crop loss about 50 per cent	Do.
Decatur and Thomas Counties, Kans.	29	8 p. m.	10 mi.		50,000	do.	Much crop damage over patch 30 miles long	Do.
Plainfield, Wis. (near)	30-31				3,500	2 hail storms	Growing crops hurt	Do.

RIVERS AND FLOODS

By R. E. SPENCER

Mississippi drainage.—Of the floods in the tributaries of the lower Ohio, only those in the Green and Cumberland Rivers were of importance. The Cumberland rise was fully discussed in the June issue of this REVIEW; and of that in the Green, and in the Ohio from the mouth of the Green to the mouth of the Wabash, the official in charge of the Weather Bureau office at Evansville, Ind., reports in part as follows:

Computation from as complete a survey as it has been possible to make indicates that, in the Evansville district, fully 41,750 acres, mostly in corn, tobacco, and soy beans, were inundated by the flood waters, with a total loss of crops amounting to $1,252,500. It is estimated that $14,300 was lost from suspension of business, and that there was damage to bridges and highways amounting to $8,800.

There was no loss of stock or movable property reported, and, as a result of timely warnings, reports indicate that it was possible in a number of instances to bank considerable acreage of corn sufficiently to save the crop, the total saving amounting to several thousands of dollars.

The above flood is the first of record for the Evansville district for the month of July.

As was shown in the flood table in the June REVIEW, floods were general in the St. Louis (Mo.,) river district during that month, notably in the lower Missouri and in the Grand, Osage, Meramec, and Black (of Missouri) Rivers. The Meramec flood continued into July, and a second serious rise occurred in the Grand following the 22d of this month. In addition, and particularly during June, there were many instances of direct damage to fields by excessive and continuous rainfall, as well as numerous overflows, destructive principally to bridges and highways, from small streams. From all causes the major damage was, of course, to the corn crop, and in somewhat lesser measure to shocked wheat. For the two-month period the proportion of this crop loss attributable to overflow from the major streams alone is conservatively estimated at $1,500,000; and, as stated above, there was, of course, very material additional damage done along small creeks and directly by the rains themselves. Flood warnings, which were timely and accurately verified, proved of value principally in enabling farmers to move shocked wheat to places of safety. The saving thus effected amounted to about $50,000.

The Illinois River flood of July was without consequence, except for a temporary interference with engineering operations along the upper river.

In the Cairo (Ill.) district the combined losses occasioned by the floods in the Mississippi River from Cape Girardeau to New Madrid, Mo., and in the Ohio River below the mouth of the Wabash were also decidedly heaviest in crops. A table of losses for this district follows:

Tangible property	$20, 300
Farm property:	
Matured crops	40, 000
Prospective crops	1, 308, 625
Live stock	2, 000
Suspension of business	49, 000
Total	1, 419, 925

Value saved through Weather Bureau warnings, $134,000.

Of the floods in the Memphis district, comprising the Mississippi from New Madrid to the mouth of the Arkansas, and the St. Francis River in Arkansas, the official in charge of the Weather Bureau office at Memphis reported as follows:

THE MISSISSIPPI RIVER

Beginning with the month of April, 1928, the Mississippi River in this district, in a series of rises, alternating with falls of successively shorter duration, reached higher crests each month, culminating in a crest stage of 34 feet at Cottonwood Point on July 7 and 8; 35.9 feet at Memphis on July 10, and 45.7 feet at Helena on July 12 and 13. At Memphis the river was above the bank full stage two days early in May 12 days in June, and 16 days in July, and at Helena on 4 days in April, 11 daysin May, 13 days in June, and 20 days in July.

The crest stages in this district were the greatest of record for July, exceeding the previous maximum for that month at Memphis by 2.2 feet, and the crest stage at Helena was 4.1 feet greater than any recorded July stage at that place.

THE ST. FRANCIS RIVER IN ARKANSAS

A series of heavy rains in the first two decades of June caused three separate rises in the St. Francis River, culminating in the highest stage of record or tradition at St. Francis, Ark., at 11 a. m., on June 26—26.7 feet, or 0.3 foot higher than the previous highest stage of April 18, 1927. At Marked Tree, Ark., the rise began on June 9, when the stage was at 7.1 feet, nearly 10 feet below the flood stage. It continued steadily, reaching the flood stage of 17 feet on June 26 and cresting at 18.3 feet on July 5. The fall at Marked Tree was slow, the river remaining at 18.3 feet from July 5 to 10, inclusive, and not passing below the flood stage until July 20.

Backwater from the Mississippi River, augmented by flood water from the upper St. Francis and Little Rivers, appeared in places in the lower St. Francis Basin as early as June 14, and near Marianna, in Lee County, by June 25. The water varied in depth from 1 to 7 feet, but averaged 3 to 4 feet, and receded July 18 to 20. The water reached a greater depth in the backwater area of the lower St. Francis Basin than ever known before in July, and receded too late in the season to permit of raising any crops of consequence in the area that overflowed.

Losses were extremely high, as, with a flood of such severity thus late in the growing season, they were bound to be. Weather Bureau flood warnings of a high order of accuracy, and issued well in advance of the destructive stages, were the means of a saving of $1,285,000 in matured crops hastily harvested and preserved by safe housing, in matured crops protected by temporary levees, in levee protection, in the adjustment of logging and other operations to cope as well as possible with flood conditions; but the reported unavoidable losses nevertheless totaled $6,070,000, exclusive of railroad losses. In his comment on losses the official in charge at Memphis states:

The loss of prospective crops in the backwater area is greater than that of any previous year of record on account of the lateness of the flood. Even last year, 1927, the water in the overflowed area receded in time to make corn and forage crops. The reported losses are itemized below, and in addition to these a total expense for the cost of building private levees, amounting to $37,558.77 was reported to this office, and this is, doubtless, only a small part of the total expended for this purpose.

Table of flood losses, Memphis (Tenn.) district, June-July, 1928

Tangible property	$500, 000
Farm property:	
Matured crops	100, 000
Prospective crops (213,325 acres)	5, 325, 000
Livestock, etc	5, 000
Suspension of business	140, 000
	6, 070, 000

Value of property saved through warnings, $1, 285, 000.

Of conditions in the Vicksburg (Miss.), district, where high water had persisted, as in the Memphis district, through spring and early summer, the official in charge of the Weather Bureau office at Vicksburg reports as follows:

Coming as a distinct flood near the middle of the summer, the present flood is without precedent, new records being made for high water at Vicksburg for the months of July and August, the previous record for August having been made in 1875.

Although no loss of human life or of livestock was reported, the damage in destruction of growing crops was extremely heavy being heightened by the fact that the region affected suffered overflow the previous year (1927), and this crop had been put in and brought to the cultivation stage by the extensive employment of credit and charity agencies; also, the subsidence of the flood mostly came too late in the season for emergency or substitute crops to be successfully grown during the present year.

Figures obtained from the Mississippi River Commission indicate that 387,712 acres, practically all in the lower Yazoo-Mississippi Delta, was flooded this summer, of which area about 94,400 acres was in growing crops at the time of submergence.

Damage to highways and bridges, while not extensive, also occurred, with various expenditures and damages, such as private and municipal levees and bulwarks, incident to flood protection, the exact amount of which can not be ascertained, much of it being intangible, as the moving away of plantation employees, owing to lack of work.

Considering all losses due to the flood in this vicinity in 1928, it is believed that a total of $1,750,000 would be a conservative estimate thereof.

Full data on the extent of overflow and the damage done in the reach of the Mississippi within the New Orleans district had not been assembled in time for inclusion in this report. A preliminary statement from New Orleans notes, however, the important similarity of the effect of the flood upon crops in that district to that in other districts to the north. A portion of this statement follows:

The time of occurrence of the rise was unfortunate for crops planted in backwater areas above the mouth of the Red Rive and in smaller areas, where the bluffs between Vicksburg and Baton Rouge are interrupted by more open areas around the mouths of small eastern tributaries of the Mississippi.

Further overflow from the open crevasse in the lower western levee, or Port Barre South Levee, of the Atchafalaya River, occurred in the neighborhood of Henderson and Breaux Bridge, St. Martin Parish. Special forecasts regarding the amount of rise, time of culmination, and subsequent recession of the overflow were supplied to the relief agencies.

Floods in Kansas.—On the Smoky Hill and Solomon Rivers of Kansas damaging overflows occurred between the 11th and 15th in the vicinity of Beloit, Niles, and Ogden, and again, following the rains of the 18th, in the vicinity of Minneapolis, Kans. The damage, principally to matured crops, was estimated at $141,600 for the first rise and at $278,000 for the second.

Miscellaneous.—In interior Ohio and Indiana considerable damage to farms resulted from heavy local rains and overflows from small creeks, and in the Weegee Valley of Ohio, where Weegee Creek was in flood on the 12th, two mines were flooded, with resultant temporary suspension of operations, several bridges were washed out, and other damage was done to an extent roughly estimated at $500,000.

The floods in the Atlantic, East Gulf, West Gulf, and Pacific drainages were in general of no consequence.

[All dates in July except as otherwise specified]

River and station	Flood stage	Above flood stages—dates		Crest	
		From—	To—	Stage	Date
ATLANTIC DRAINAGE	*Feet*			*Feet*	
Susquehanna: Oneonta, N. Y	12			12.5	23.
Santee:					
Rimini, S. C	12	2	14	13.5	5.
		16	20	13.5	18–19.
		28	(2)	13.8	31.
Ferguson, S. C	12	4	8	12.5	6.
		14	22	13.0	17.
		31	(2)		
Broad: Blairs, S. C	15	(1)	1	15.8	June 30.
Saluda: Pelzer, S. C	7	13	13	7.4	13.
Altamaha: Everett City, Ga	10	20	25	10.3	22–23.
EAST GULF DRAINAGE					
Tombigbee: Lock No. 4, Demopolis, Ala	39	(1)	2	42.3	June 30.
Etowah: Canton, Ga	11	14	14	13.1	14.

[1] Continued from last month. [2] Continued at end of month.

River and station	Flood stage	Above flood stages—dates		Crest	
		From—	To—	Stage	Date
MISSISSIPPI DRAINAGE	*Feet*			*Feet*	
Ohio: Evansville, Ind	35	1	8	38.4	5.
Dam No. 48, Cypress, Ind	35	3	8	36.9	6.
Shawneetown, Ill	35	3	10	37.0	7.
Cairo, Ill	45	1	9	45.6	5–7.
Tuscarawas: Gnadenhutten, Ohio	9	22	22	9.7	22.
Green:					
Lock No. 6, Brownsville, Ky	30	1	2	30.6	1.
Lock No. 4, Woodbury, Ky	33	June 30	4	39.0	2.
Lock No. 2, Rumsey, Ky	34	June 30	10	38.3	6.
Barren: Bowling Green, Ky	20	1	2	22.4	2.
Tippecanoe: Norway, Ind	6	2	2	6.1	2.
White, West Fork: Edwardsport, Ind	15	9	9	15.6	9.
Cumberland:					
Carthage, Tenn	40	1	4	45.2	2.
Nashville, Tenn	40	(1)	7	42.9	5.
Clarksville, Tenn	46	(1)	8	48.0	2.
Tennessee:					
Rockwood, Tenn	20	1	2	23.4	1.
Clinch: Clinton, Tenn	25	(1)	1	28.6	June 30.
Mississippi:					
New Madrid, Mo	34	(1)	12	36.0	6–7.
Memphis, Tenn	35	3	14	35.9	10.
Helena, Ark	44	(1)	17	45.7	12–13.
Arkansas City, Ark	48	(1)	22	52.6	6–8.
Greenville, Miss	42	(1)	21	45.5	6–11.
Vicksburg, Miss	45	(1)	28	49.3	11–14.
Natchez, Miss	46	5	28	48.5	18–19.
Angola, La	45	11	27	46.0	18–21.
Baton Rouge, La	35	10	29	36.4	19–21, 23.
Donaldsonville, La	28	17	25	28.2	21–23.
Illinois:					
Morris, Ill	13	5	8	14.7	6.
Peru, Ill	14	4	17	17.3	7–8.
		22	25	14.4	23.
Henry, Ill	10	8	15	10.8	10–11.
Havana, Ill	14	8	18	14.4	12–14.
Beardstown, Ill	14	12	17	14.1	13–16.
Meramec:					
Pacific, Mo	11	(1)	1	14.5	June 30.
Valley Park, Mo	14	(1)	1	18.2	June 30.
St. Francis:					
St. Francis, Ark	17	(1)	11	20.7	June 26.
Marked Tree, Ark	17	(1)	20	18.3	5–10.
Smoky Hill: Solomon, Kans	24	11	12	24.2	11.
Solomon: Beloit, Kans	18	10	10	20.2	10.
		13	15	24.2	14.
		20	22	24.2	21.
		31	(2)		
Grand, West Fork: Gallatin, Mo	20	22	25	32.7	24.
Grand: Chillicothe, Mo	18	22	26	27.4	25.
Grand, Thompsons Fork: Trenton, Mo	20	22	23	22.5	23.
Arkansas: Yancopin, Ark	29	(1)	27	39.1	1–5.
White:					
Newport, Ark	26	(1)	4	32.6	June 25.
Georgetown, Ark	22	(1)	12	29.9	June 27.
De Valls Bluff, Ark	24	(1)	9	28.5	June 28–29.
Clarendon, Ark	30	(1)	11	34.9	1.
Black:					
Corning, Ark	11	(1)	13	15.0	June 19.
Black Rock, Ark	14	(1)	15	26.6	June 22.
Cache: Patterson, Ark	9	(1)	9	11.8	June 27–28.
Sulphur: Finley, Tex	24	(1)	3	28.6	June 29.
Cypress: Jefferson, Tex	18	(1)	2	19.3	1.
Atchafalaya: Melville, La	37	12	29	37.8	23.
WEST GULF DRAINAGE					
Trinity:					
Dallas, Tex	25	29	29	25.1	29.
Trinidad, Tex	28	2	3	28.4	3.
PACIFIC DRAINAGE					
Colorado: Parker, Ariz	7	(1)	20	11.9	June 8.
		26	27	7.0	26–27.
Columbia: Marcus, Wash	24	(1)	19	34.2	May 30–31.

[1] Continued from last month. [2] Continued at end of month.

MEAN LAKE LEVELS DURING JULY, 1928

By UNITED STATES LAKE SURVEY

[Detroit, Mich., August 4, 1928]

The following data are reported in the Notice to Mariners of the above date:

Data	Lakes [1]			
	Superior	Michigan and Huron	Erie	Ontario
Mean level during July, 1928:	*Feet*	*Feet*	*Feet*	*Feet*
Above mean sea level at New York	602.87	580.41	572.71	246.73
Above or below—				
Mean stage of June, 1928	+0.40	+0.29	+0.32	+0.14
Mean stage of July, 1927	+0.23	+0.83	+0.54	+0.72
Average stage for July, last 10 years	+0.80	+0.25	+0.39	+0.53
Highest recorded July stage	−0.95	−3.17	−1.70	−1.99
Lowest recorded July stage	+2.01	+1.87	+1.50	+2.14
Average departure (since 1860) of the July level from the June level	+0.21	+0.06	−0.04	−0.04

[1] Lake St. Clair's level: In July, 1928, 575.54 feet.

EFFECT OF WEATHER ON CROPS AND FARMING OPERATIONS, JULY, 1928

By J. B. KINCER

General summary.—During the first decade of July there was a change from the cool, cloudy, and wet weather, which had characterized conditions for more than a month in Central and Northern States, to warm, sunny conditions, which were very favorable for the growth of crops and farm work. Warm-weather vegetation especially made rapid advance, as the soil moisture was abundant in most sections. Some complaints of poor cultivation, due to the previous wet weather, continued, however, although farm work made good progress in most of the South. The weather in the Great Plains was especially favorable, and showers in the Pacific Northwest were helpful, but much of the Southwest remained dry, and only irrigated crops did well.

Mostly favorable conditions continued during the second decade, with moderate temperatures prevailing, and rather well-distributed showers over the greater portion of the country. Harvesting and threshing were interrupted to some extent in the Great Plains area, but the warmer weather and much sunshine in the interior valleys were especially favorable for corn. Rain was still needed in the Southwest, but over most of the country there was an unusually generous supply of soil moisture, although in the far Northwest dry-land farms needed rain.

Weather conditions remained generally favorable for agricultural interests during the last decade in most parts east of the Rocky Mountains. A general, moderate, warm rain would have been helpful over considerable sections of the interior, but, as a general rule, soil moisture was more than usually favorable in the principal agricultural sections, with no extensive area suffering from drought. In the Southwest further showers were welcome, with the drought broken in Texas, except for parts of the coastal localities and the southwest. In the Atlantic coast districts the weather was favorable for crop growth, and in the Great Plains harvest made generally good advance, except for some local delay by showers. West of the Rockies conditions were favorable for irrigated crops, but it was too hot and dry for unirrigated vegetation.

Small grains.—During the first decade timely dry, sunshiny weather favored the harvest of winter wheat, and this work made good progress, except for some interruption by rains in Kansas. Cutting had begun north to the southern portions of Pennsylvania and Ohio and to the northern portions of the belt in the Great Plains. In eastern Kansas the bulk of wheat had been cut, while farther south conditions were favorable for harvest and threshing.

During the second decade the harvest of winter wheat was interrupted to a considerable extent by rains in the Atlantic area, but cutting made rather favorable advance in general. During the last part of the month rain interrupted the harvesting of this crop in some late sections of the western belt, but wheat harvest had been mostly completed and threshing was well along.

Spring wheat made good development during the first decade, under favorable weather conditions, and was mostly headed in the heavy producing sections; the crop showed general improvement and appeared to be in fair to very good condition. It continued to make fair to very good progress during the second decade, with indications of heads filling well, though there was some premature ripening locally, due to dryness. The weather during the last decade continued mainly favorable for ripening the grain and for harvest in the spring-wheat area with cutting begun in North Dakota, but the unusually warm weather in the Pacific Northwest caused considerable damage to immature grain.

Corn.—During the first decade the weather was generally favorable for corn, with progress mostly excellent in the main producing sections. In the Ohio Valley warmth and ample soil moisture promoted rapid growth and in Iowa development and condition were generally excellent, with the crop averaging waist-high. In the Great Plains corn made good to excellent advance and was tasseling north to northern Kansas. In the South progress varied from fair to excellent, and in the East the weather was generally favorable, while from the Great Lakes westward much improvement was noted. The weather continued mostly favorable during the second decade and progress was mostly good to excellent. There was still some complaint of lack of cultivation in the eastern half of the belt and in some southern sections of the Great Plains. In Iowa the crop was beginning to tassel, with a little shooting and silking, and in the Great Plains advance was excellent, with some tasseling north to South Dakota.

During the last decade corn made very good to excellent progress in practically all of the main producing sections and was silking and tasseling in the Ohio Valley, with some ears showing. Progress and condition were very good in Iowa, with the crop mostly tasseled and half silked; stalks were largely in silk in Missouri and a few roasting ears were showing. Fair to excellent advance was reported in the Great Plains, with the crop generally tasseled and much of it silking, but progress varied widely in the South; good advance was indicated in the East and from the Great Lakes westward.

Cotton.—During the first decade cotton made very good growth in the Carolinas, with squares and bloom becoming increasingly abundant in South Carolina, but in Georgia cultivation was badly needed, with the plants making sappy growth and some poor stands reported. In the central part of the belt progress ranged from mostly fair to very good and the crop was generally late, while in Arkansas and Louisiana progress was very good. In Oklahoma very good advance was reported, with early plants setting squares and blooming; but in Texas only fair to good progress was made, although picking and ginning made good advance in the extreme south.

During the second decade cotton made mostly good growth in the Carolinas and Georgia, but plants were sappy, due to frequent rains, and in Georgia there were complaints of ceasing to fruit well and some shedding. In the central part of the belt progress varied from poor to locally good, but with complaints of lateness, lack of cultivation, and some abandoned fields on northern lowlands.

In Arkansas progress was poor to only fair in some wet portions, but mostly very good elsewhere, while in Louisiana growth was good; in Oklahoma it was rather too cool and wet, but early plants were fruiting nicely. In Texas progress and condition were fair to good, except poor in some dry sections; picking and ginning made good advance in the south.

During the last decade growth of plants was very good in the Carolinas, although the crop continued late, as a rule, and in Georgia cotton showed further improvement, with bolls forming well and less shedding. In the central part of the belt progress was fair to very good, while in Arkansas cotton made very good advance, except in some areas where it was still too wet. In Louisiana growth of plants was good, but there were

some reports of shedding rather badly. In Oklahoma progress and condition were fair to good, but warm, dry weather was needed in some parts where shedding was reported. In Texas the drought was broken, except in parts of the southwest and lower coast sections, where the crop made poor advance; elsewhere conditions were generally favorable and progress was fair to very good.

Miscellaneous crops.—Pastures made mostly satisfactory advance east of the Mississippi River during the month, and in the Great Plains area good to excellent condition was noted. Ranges in the Rocky Mountain area did well, except that in the more southern part and also in the Southwest there was need of moisture, and ranges were generally dry west of the mountains. Except for some local interruption, haying made good advance. Livestock continued to do well.

Potatoes did well generally, except that, at the close, they were reported blighting badly on Long Island, and some slight blight was indicated in the eastern Ohio Valley. Truck crops did well rather generally. Sugar cane made excellent advance in Louisiana and sugar beets did well, although at the close of the month they needed rain in Utah. Tobacco curing progressed well in the Southeast, and good advance was made elsewhere. Citrus grew well during the month, and deciduous fruits made normal growth, but there were complaints that peaches were rotting and dropping in parts of the Southeast toward the end of the month.

WEATHER OF THE ATLANTIC AND PACIFIC OCEANS

NORTH ATLANTIC OCEAN

By F. A. YOUNG

Judging from reports received up to time of writing, July was one of the quietest months on record over the North Atlantic, as only 10 vessels have forwarded storm reports, with a maximum wind force of 9. There was only one well-developed disturbance of any intensity during the month, and this originated in the first decade, and will be described later. Under these conditions it was not considered advisable to publish the usual charts.

As is often the case during a month of moderate weather, fog was unusually prevalent. Over the steamer lanes, west of the twentieth meridian, fog was reported on from 14 to 27 days, the latter number occurring in the 5° square between the fortieth and forty-fifth parallels and sixty-fifth to seventieth meridians.

TABLE 1.—*Averages, departures, and extremes of atmospheric pressure at sea level, 8 a. m. (seventy-fifth meridian), North Atlantic Ocean, July, 1928*

Stations	Average pressure	Departure [1]	Highest	Date	Lowest	Date
	Inches	*Inch*	*Inches*		*Inches*	
Julianehaab, Greenland	29.80	([2])	30.24	29th	29.36	6th.
Belle Isle, Newfoundland	29.83	−0.04	30.22	13th	29.46	20th.
Halifax, Nova Scotia	29.96	+0.04	30.24	14th	29.70	29th.
Nantucket	29.97	−0.01	30.24	31st	29.72	23d.
Hatteras	30.03	+0.01	30.24	31st	29.86	6th.
Key West	30.04	+0.03	30.12	25th	29.98	19th.
New Orleans	30.04	+0.04	30.14	29th [3]	29.96	11th.
Cape Gracias, Honduras	29.90	0.00	29.94	5th [3]	29.80	18th.
Turks Island	30.09	+0.08	30.18	24th	29.90	1st.
Bermuda	30.22	+0.11	30.36	12th [3]	30.04	23d.
Horta, Azores	30.24	−0.03	30.46	8th [3]	29.96	30th.
Lerwick, Shetland Islands	29.78	−0.02	30.19	16th	29.44	29th.
Valencia, Ireland	30.12	+0.14	30.49	16th	29.76	27th.
London	30.10	+0.12	30.44	17th	29.67	28th.

[1] From normals shown on Hydrographic Office Pilot Chart based on observations at Greenwich mean noon, or 7 a. m., seventy-fifth meridian.
[2] No normal available.
[3] And on other dates.

On the 1st and 2d an area of low pressure was off the north coast of Scotland, and on the latter date land stations in the British Isles reported southwest winds of force 7, although all reports that have been received from vessels in the vicinity give moderate winds.

On the 5th and 6th there was a second LOW in nearly the same location, and on the 5th low pressure also occurred over the Straits of Belle Isle; both LOWS were accompanied by moderate weather.

From the 7th to 11th the only disturbance of any extent during the month covered the eastern section of the steamer lanes; this reached its greatest force on the 10th when moderate south to southwesterly gales prevailed over the area between the forty-fifth and fifty-fifth parallels and the fifteenth to thirtieth meridians.

From the 12th to the 30th, while there were depressions over different sections of the ocean, moderate weather was the rule, and during this period winds of over force 6 were rare.

On the 31st the American S. S. *McKeesport* encountered a northeasterly gale, as shown by report in table. The storm area was evidently very limited, as other vessels near by reported moderate winds.

Note.—Am. S. S. *Pennsylvanian*, Capt. A. C. Keene; observer, J. M. Mikkelsen, Charleston to New York. July 8, 8 a. m., seventy-fifth meridian time, in 33° 50′ N., 74° 56′ W. Sea smooth, weather cloudy, St.-Cu. 6, barometer 30.09 inches, air 80°, wet bulb 78°, water 76°, visibility fair. Observed a large waterspout drawing water, about 6 to 7 miles to eastward, that lasted about 15 minutes. The upper part was a short and broad solid column with a narrow white streak in the center. In the middle it was broken and the lower part was more hazy and appeared as if water were splashing out to each side. A heavy rain squall followed about half an hour later. Rest of day was fine and clear.

OCEAN GALES AND STORMS, JULY, 1928

Vessel	Voyage: From—	Voyage: To—	Position at time of lowest barometer: Latitude	Position at time of lowest barometer: Longitude	Gale began	Time of lowest barometer	Gale ended	Lowest barometer	Direction of wind when gale began	Direction and force of wind at time of lowest barometer	Direction of wind when gale ended	Highest force of wind and direction	Shifts of wind near time of lowest barometer
NORTH ATLANTIC OCEAN			° ′	° ′				Inches					
Coamo, Am. S. S.	San Juan	New York	33 43 N.	70 57 W.	July 1	4a, 1	July 1	30.00	WSW	SW., 4	SW	—, 8	
Winnebago, Br. S. S.	Shields	do	57 48 N.	15 39 W.	8	5a, 8	9	29.40	SSW	SSW., 7	WSW	SW., 8	SSW.-W.
Mississippi, Br. M. S.	London	Boston	48 10 N.	24 22 W.	9	Noon, 9	10	29.92	SW	SW., 7	WNW	SW., 9	Steady.
Kerhonkson, Am. S. S.	Manchester	New York	51 06 N.	18 49 W.	9	4p, 10	10	29.72	S	S., 8	SSW	S., 8	S.-SSW.
American Farmer, Am. S. S.	London	do	47 08 N.	27 08 W.	9	Noon, 10	10	29.82	SW	SW., 8	W	SW., 8	SW.-W.
City of Alton, Am. S. S.	Rotterdam	do	43 06 N.	42 54 W.	21	—, 22	22	29.84	SW	SW., 8	W	SW., 8	SW.-W.
Do	do	do	41 14 N.	56 30 W.	24	—, 25	25	29.74	SSW	WNW., 7	W	SSW., 8	SSW.-W.
McKeesport, Am. S. S.	Havre	do	49 40 N.	15 40 W.	31	4a, 31	31	29.62	NE	NE., 5	NE	NE., 9	NE.-NNW.
NORTH PACIFIC OCEAN													
Hanoi, Fr. S. S.	Gulf of Tonkin.	Hong Kong	20 00 N.	110 00 E.	15	Noon, 15	15	29.06		W., 12		W., 12	
Makaweli, Am. S. S.	Hawaii	San Francisco	37 20 N.	124 12 W.	18	Midt, 18	19	29.93	NW	NW., —	NW	NNW., 8	Steady.
Cellina, It. M. S.	San Francisco	Panama	13 95 N.	92 12 W.	20	—, 20	20	29.74	N	N., 12	N	N., 12	Do.
Los Angeles, Am. S. S.	Los Angeles	Balboa	13 31 N.	93 44 W.	22	2a, 22	22	29.90	E	E., 8	E	E., 8	Do.
Induna, Br. S. S.	Vancouver	Boston	20 20 N.	107 00 W.	28	4p, 28	29	29.86	SE	SE., —	SE	SSE., 12	SE.-SSE.
Pres. Harrison, Am. S. S.	Honolulu	Kobe	32 20 N.	141 05 E.	29	Midt, 31	Aug. 1	28.73	E	S., 2	N	SE., 11	E.-S.-N.
SOUTH PACIFIC OCEAN													
Makura, Br. S. S.	San Francisco	Sydney	36 00 S.	158 00 E.	7	1a., 7	July 7	29.26	SSE	SSW., 11	WSW	SW., 11	SSW.-WSW.
Do	Sydney	San Francisco	28 20 S.	166 49 W.	19	1a., 20	20	29.54	ENE	NE., —	NE	—, 10	ENE.-N.

NORTH PACIFIC OCEAN

By WILLIS E. HURD

The North Pacific high-pressure area off the coast of California continued strongly developed throughout July and with no cyclones entering upon its boundaries.

The Aleutian cyclone, frequently absent at this time of year, was central over Bering Sea, lowest average pressure determined being 29.72 inches, at St. Paul, Pribilof Islands. For the entire Aleutian region, however, pressures were considerably below normal, as will be observed in the following table:

TABLE 1.—*Averages, departures, and extremes of atmospheric pressure at sea level at indicated hours, North Pacific Ocean, July, 1928*

Stations	Average pressure	Departure from normal	Highest	Date	Lowest	Date
	Inches	*Inch*	*Inches*		*Inches*	
Dutch Harbor [1] [2]	29.78	−0.24	30.10	9th	29.36	28th.
St. Paul [1] [2]	29.72	−0.13	30.18	3d [7]	29.24	29th.
Kodiak [1] [3]	29.83	−0.13	30.28	25th	29.32	18th.[7]
Midway Island [1] [4]	30.10	+0.02	30.22	7th [7]	29.90	29th.
Honolulu [5]	30.03	+0.01	30.14	2d	29.88	20th.
Juneau [5]	30.02	−0.03	30.33	24th	29.60	3d.
Tatoosh Island [5] [6]	30.04	−0.03	30.17	12th	29.71	3d.
San Francisco [5] [6]	29.93	−0.02	30.07	23d	29.77	19th.
San Diego [5] [6]	29.91	+0.02	30.06	22d	29.81	27th.

[1] P. m. observations only.
[2] For 29 days.
[3] For 27 days.
[4] For 28 days.
[5] A. m. and p. m. observations.
[6] Corrected to 24-hour mean.
[7] And on other date or dates.

The weather over all the Pacific Ocean, except for a few coastal localities, was remarkable for its utter absence of storms, however mild, a condition rarely met with even during the calmest of the summer months. The only extratropical gale reported occurred about 100 miles west of San Francisco on the afternoon of the 18th, when a northwesterly wind of force 8 was experienced by the American steamer *Makaweli* on the eastern edge of the permanent anticyclone.

The prevailing wind at Honolulu continued from the east, but the maximum wind velocity, at the rate of 29 miles an hour, was from the northeast, on the 26th.

In portions of the Tropics the weather was more or less disturbed. At least two typhoons occurred in the Far East, and in addition many LOWS in more or less weak stages of development traversed the waters of this region.

The first typhoon seems to have originated as a shallow depression about the 8th, near 15° N., 134° E. On the 12th it had increased in energy and lay off the east coast of Luzon. On the 13th and 14th it crossed the China Sea, still gathering intensity, and on the 15th burst as a dangerous storm with hurricane winds over the Gulf of Tonkin. The French steamer *Cap Lay* was wrecked at the entrance to the Haifong River and many of her passengers were lost, while numbers of small junks and other craft were lost. Capt. J. L. Cruchot, of the French steamer *Hanoi*, in a report to the Weather Bureau, said his vessel and others rode out the hurricane, which lasted from 11 a. m. to 5 p. m., in an anchorage off the northern end of the island of Hainan. He noted that much damage was done on shore in the general vicinity.

The second typhoon was discovered on the 24th, near 16° N., 142° E. On the 28th, in 24° N., 139° E., it was identified as a deep cyclone moving toward Japan. On the 29th it was central near 25° N., 141° 30′ E., and on the 30th, near 32° N., 140° E., advancing slowly upon Honshu. Press reports of August 2 from Tokyo said that the storm raged over the islands for three days, and that it was the worst in 18 years over Honshu, floods and high winds causing some loss to life and property damage amounting to many millions of dollars. At midnight of July 31 the American steamer *President Harrison*, in 32° 20′ N., 141° 05′ E., had a minimum pressure reading of 28.73 inches, highest wind velocity, force 11, from east-southeast, southeast, and north.

In the American tropics moderate to violent gales occurred on the 20th and 22d off the Guatemalan coast, and on the 28th and 29th off the Mexican coast, near Cape Corrientes, full hurricane forces being reported on the 20th and 28th. No unusual depression of the baro-

meter was noted in any instance, except that at 5 a. m. of the 29th the Japanese steamer *Kuma Maru* recorded a reading of 29.64 inches, wind east-southeast, force 8, in 19° 37′ N., 105° 45′ W. The storm of the 28th–29th was evidently cyclonic in character. The squall-like hurricane wind of the 20th seems to have been of the nature of a chubasco, and the gale of the 22d as due to a violent thunderstorm.

Frequent dense fog formed along the western half of the northern sailing routes, where, according to reports tabulated between the one hundred and eightieth meridian and the coast of northern Japan, it occurred on from 40 to 50 per cent of the number of days in the month. Several vessels in that area steamed for several days at a time through a practically unbroken layer of fog. The percentage lessened rapidly with approach from central longitudes to the American coast, and in the region of the North Pacific anticyclone fog was infrequent. Along the middle California coast, however, there was a local increase to 25 or 30 per cent.

THE AURORA OF JULY 7–8, 1928, ON THE NORTH ATLANTIC OCEAN

By WILLIS E. HURD

The extraordinarily widespread aurora of the night of July 7–8, 1928, was observed not only in North America and Europe (see pp. 280–281) but over a great area of the North Atlantic Ocean in middle as well as lower latitudes. The northernmost observation of it actually reported was from 42° 40′ N., in 68° 53′ W. The extreme western and southern observations reported were from the Gulf of Mexico, greatest longitude, 87° 50′ W., lowest latitude, 24° 08′ N., which is nearly half a degree below that of Key West. Over the main body of the ocean most reports of the phenomenon came from vessels west of the thirty-fifth meridian, between latitudes 30° and 42° N.

Generally speaking, the observational period lengthened with westward increase in longitude, some vessel observers toward the American coast reporting the display as continuous, with fluctuations in brilliancy, from 8 p. m. of the 7th until dawn of the 8th, but with the most active period in most instances preceding midnight. In some central localities the illumination was noted as covering the sky, but in the Gulf of Mexico it was seen only along the northern horizon, rising to a height of from 20° to 28°.

In central longitudes and in the Mediterranean Sea the aurora was reported as visible only during the early morning hours, or at least as being brightest after midnight.

The lights were almost generally described as consisting of mixed streamers and patches, more whitish than otherwise, but frequently of colors ranging therefrom to various shades of red, purple, and light green.

Press comments touched upon the bad radio reception noticed in the United States that night. At sea varying conditions of good and poor receptivity prevailed. In 39° 20′ N., 73° 30′ W., the American steamer *Ponce* reported "static almost entirely absent. Reception excellent on commercial and lower wave lengths." Near by the Panaman steamer *Manaqui* found "little interference due to static." In 42° 40′ N., 68° 53′ W., the United States Coast Guard destroyer *Wainwright* reported "unusually good reception" in a communication to the Hydrographic Office. In 35° 53′ N., 34° 46′ W., the American steamer *Montgomery City* found "no change in radio signals." Contrary to this was the statement from the Dutch steamer *Yselhaven*, in 35° N., 48° W., of "very bad reception during the whole night."

CLIMATOLOGICAL TABLES[1]

CONDENSED CLIMATOLOGICAL SUMMARY

In the following table are given for the various sections of the climatological service of the Weather Bureau the monthly average temperature and total rainfall; the stations reporting the highest and lowest temperatures, with dates of occurrence; the stations reporting the greatest and least total precipitation; and other data as indicated by the several headings.

The mean temperature for each section, the highest and lowest temperatures, the average precipitation, and the greatest and least monthly amounts are found by using all trustworthy records available.

The mean departures from normal temperatures and precipitation are based only on records from stations that have 10 or more years of observations. Of course, the number of such records is smaller than the total number of stations.

Condensed climatological summary of temperature and precipitation, by sections, July, 1928

Section	Temperature								Precipitation					
	Section average	Departure from the normal	Monthly extremes						Section average	Departure from the normal	Greatest monthly		Least monthly	
			Station	Highest	Date	Station	Lowest	Date			Station	Amount	Station	Amount
	°F.	°F.		°F.			°F.		In.	In.		In.		In.
Alabama	80.6	+0.5	Evergreen	101	27	3 stations	60	[2]13	5.11	-0.34	Seale	10.84	Tuscumbia	1.34
Arizona	82.0	+0.7	3 stations	119	[2]24	Big Spring Ranger Station.	31	13	1.55	-0.84	Young	5.11	8 stations	0.00
Arkansas	80.3	+0.3	Hope	102	23	Dutton	52	14	3.66	-0.16	Waters	9.84	Gilbert	0.46
California	72.1	-0.4	Palm Springs	120	24	Helm Creek	26	1	0.01	-0.06	Montague	0.57	199 stations	0.00
Colorado	65.7	-0.9	Lamar	105	5	Pearl	20	8	2.20	-0.05	Auldhurst	6.58	Glenwood Springs	0.08
Florida	81.5	+0.3	2 stations	101	29	New Smyrna	62	6	7.37	+0.14	Hilliard	17.44	Miami Beach	1.32
Georgia	80.3	+0.5	Eastman	101	5	Clayton	52	7	6.80	+1.09	Blue Ridge	11.58	Goat Rock	2.38
Idaho	69.0	+0.8	Orofino	114	26	Rostetter Ranger Station.	25	1	0.48	-0.21	Orofino	2.00	4 stations	0.00
Illinois	76.3	+0.3	2 stations	99	[2]7	Mount Carroll	44	7	3.56	+0.26	Rochelle	7.42	Mount Carmel	0.34
Indiana	74.8	-0.5	Rochester	99	7	Goshen	43	29	3.55	+0.15	Veedersburg	9.00	Boonville	0.63
Iowa	73.9	+0.2	2 stations	98	6	Mason City	43	28	4.43	+0.61	Mount Ayr	9.32	Estherville	0.65
Kansas	77.5	-0.8	2 stations	105	4	2 stations	52	[2]8	4.38	+1.03	Lincoln	12.77	Johnson	0.62
Kentucky	77.0	+0.1	Middlesboro	100	11	Dix Dam	50	29	4.07	-0.10	Frankfort	9.80	Marion	0.45
Louisiana	82.0	+0.4	Dodson	103	4	Angola	63	28	6.27	+0.05	Burrwood	12.75	Elizabeth	2.38
Maryland-Delaware	75.7	+0.5	Bell, Md.	99	8	Oakland, Md.	40	30	4.30	-0.03	Pleasant Hill, Md.	8.20	Takoma, Md.	1.29
Michigan	68.7	0.0	Houghton Lake	98	9	Humboldt	32	30	2.67	-0.27	Croswell	9.95	Webber Dam	0.20
Minnesota	69.3	-0.1	New Ulm	98	6	Meadowlands	38	28	4.14	+0.67	Virginia	7.37	Fairmont	0.44
Mississippi	81.7	+0.9	Aberdeen	103	[2]3	Hernando	58	16	4.79	-0.17	Poplarville	10.46	University	0.70
Missouri	77.2	-0.2	Clinton	102	21	Louisiana	48	29	2.97	-1.08	Grant City	7.02	Morehouse	0.34
Montana	66.3	+0.1	3 stations	104	[2]14	Adel	29	17	2.47	+0.93	Vida	6.21	Trout Creek	0.30
Nebraska	74.0	-0.6	Santee	104	6	Fort Robinson	40	8	3.99	+0.59	Wauneta	12.71	Fort Robinson	0.80
Nevada	73.6	+0.6	Logandale	114	[2]24	Rye Patch	32	1	0.16	-0.22	Arthur	1.19	12 stations	0.00
New England	69.8	+0.8	3 stations	98	[2]8	Somerset, Vt.	34	31	4.45	+0.68	Fort Kent, Me.	8.29	Bloomfield, Vt.	1.40
New Jersey	74.2	+0.8	4 stations	96	[2]8	Charlotteburg	41	30	6.86	+2.05	Dover	10.22	Moorestown	2.21
New Mexico	72.9	+0.5	Carlsbad	110	2	Selsor Ranch	25	1	1.92	-0.70	Pinos Altos	8.09	San Marcial	T.
New York	70.4	+0.8	2 stations	100	[2]4	Indian Lake	34	26	4.72	+0.80	Boyds Corner	8.70	Lauterbrunnen	0.48
North Carolina	77.4	+1.0	2 stations	100	[2]5	Mount Mitchell	45	2	4.87	-1.26	Chadbourn	13.57	Mount Airy	1.35
North Dakota	67.4	-0.1	Powers Lake	96	23	Hansboro	38	29	5.05	+2.44	Berthold Agency	12.22	Alpha	1.77
Ohio	73.7	+0.2	4 stations	97	[2]20	Mount Vernon	45	31	4.75	+0.96	Ellsworth	9.27	Mount Healthy	1.29
Oklahoma	80.8	-0.7	Hobart	108	16	Boise City	54	22	4.01	+1.23	Webbers Falls	10.56	Guthrie	0.64
Oregon	68.4	+1.5	Pilot Rock	116	25	Fremont	24	18	0.32	-0.16	Astoria	1.42	9 stations	0.00
Pennsylvania	72.8	+0.9	5 stations	96	[2]4	2 stations	40	[2]30	5.44	+1.09	Quakertown	11.81	Philadelphia (Point Breeze).	2.37
South Carolina	79.5	-0.2	Calhoun Falls	100	5	2 stations	58	[2]1	6.81	+0.88	Marion	13.34	Santuck	1.34
South Dakota	72.2	+0.2	Wagner	105	6	Oelrichs	40	9	2.92	+0.09	Castlewood	6.31	Ottumwa	0.74
Tennessee	78.3	+1.0	4 stations	98	[2]3	Elkmont	48	1	3.57	-0.85	Liberty	7.44	Dresden	T.
Texas	83.6	+0.7	Cameron	109	13	O2 Ranch	43	[2]21	2.70	+0.09	Seminole	8.25	2 stations	0.00
Utah	71.7	+0.1	St. George	110	26	3 stations	21	7	0.48	-0.45	Escalante	1.82	5 stations	0.00
Virginia	76.0	+0.9	3 stations	100	[2]4	Burkes Garden	45	15	3.44	-1.22	Wallaceton	9.47	Ivanhoe	1.47
Washington	68.5	+1.9	Wahluke	118	24	Bumping Lake	32	14	0.77	+0.12	Lost Creek	2.55	4 stations	0.00
West Virginia	73.5	+0.4	Point Pleasant	102	22	Bayard	35	30	4.23	-0.10	Dam 13, Ohio River	8.97	Upper Tract	1.10
Wisconsin	69.3	0.0	2 stations	97	[2]7	Long Lake	31	29	3.81	+0.14	Antigo	8.52	Prairie du Sac	0.94
Wyoming	64.6	-1.1	Wheatland	105	5	Foxpark	23	[2]8	2.09	+0.76	Knowles	5.44	Green River	0.18
Alaska														
Hawaii	74.6	+0.4	Waialua Mill	94	[2]25	Volcano observatory	52	[2]7	8.70	+2.60	Honomanu Valley	31.85	Mahukona	0.00
Porto Rico	78.8	+0.1	Rio Piedras	96	14	Jayuya	57	25	5.42	-1.09	Maricao	13.85	Santa Rita	0.40

LATE REPORTS, MAY AND JUNE, 1928

Alaska:														
May	41.0	0.0	2 stations	76	31	Barrow	-2	17	1.97	+0.54	Latouche	16.59	2 stations	T.
June	52.3	+0.3	2 stations	88	[2]8	Barrow	13	2	1.78	-0.05	Chignik	16.24	Barrow	T.
Hawaii, June	73.5	+0.4	2 stations	92	1	2 stations	52	[2]8	4.07	-0.61	Puu Kukui (upper)	20.00	9 stations	0.00

[1] For description of tables and charts, see Review, January, 1928, p. 29.

[2] Other dates also.

TABLE 1.—*Climatological data for Weather Bureau stations, July, 1928*

District and station	Elevation of instruments: Barometer above sea level	Elevation of instruments: Thermometer above ground	Elevation of instruments: Anemometer above ground	Pressure: Station reduced to mean of 24 hours	Pressure: Sea level, reduced to mean of 24 hours	Pressure: Departure from normal	Temperature of the air: Mean max. + mean min. ÷ 2	Temperature: Departure from normal	Temperature: Maximum	Temperature: Date	Temperature: Mean maximum	Temperature: Minimum	Temperature: Date	Temperature: Mean minimum	Temperature: Greatest daily range	Mean wet thermometer	Mean temperature of the dew point	Mean relative humidity	Precipitation: Total	Precipitation: Departure from normal	Precipitation: Days with 0.01, or more	Wind: Total movement	Wind: Prevailing direction	Wind: Maximum velocity: Miles per hour	Wind: Maximum velocity: Direction	Wind: Maximum velocity: Date	Clear days	Partly cloudy days	Cloudy days	Average cloudiness, tenths	Total snowfall	Snow, sleet, and ice on ground at end of month
	Ft.	Ft.	Ft.	In.	In.	In.	°F.	°F.	°F.		°F.	°F.		°F.	°F.	°F.	°F.	%	In.	In.		Miles								0-10	In.	In.
New England							69.8	+0.9										80	4.05	+0.6										5.5		
Eastport	76	67	85	29.84	29.92	-0.01	61.3	+0.9	84	18	70	50	13	53	29	58	56	83	3.20	+0.1	11	5,298	s.	28	se.	23	3	10	18	7.2	0.0	0.0
Greenville, Me.	1,070	6	----	28.79	29.92	------	65.4	------	86	11	76	36	7	55	36	----	----	----	3.86	------	13	------	nw.	----	------	----	10	12	9	----	0.0	0.0
Portland, Me.	103	82	117	29.84	29.96	+.01	69.0	+0.9	90	18	77	55	30	61	28	63	59	73	2.52	-0.7	14	5,239	sw.	26	nw.	30	20	4	7	4.1	0.0	0.0
Concord	289	70	79	29.63	29.93	-.03	69.8	+1.3	93	8	81	45	30	59	39	----	----	----	6.04	+2.5	11	3,271	s.	20	w.	16	11	12	8	5.2	0.0	0.0
Burlington	403	11	48	29.49	29.92	-.02	69.8	-0.5	91	9	79	49	21	60	29	----	----	----	2.38	-1.1	13	5,332	s.	23	s.	15	8	12	11	5.7	0.0	0.0
Northfield	876	12	60	29.02	29.94	.00	66.4	+0.5	89	8	78	41	21	54	36	65	63	87	1.99	-1.7	13	3,928	s.	22	sw.	16	1	21	9	6.6	0.0	0.0
Boston	125	115	188	29.81	29.94	-.02	73.2	+1.5	94	8	81	57	7	65	32	66	62	72	4.14	+0.6	11	5,516	sw.	24	nw.	4	11	10	10	5.3	0.0	0.0
Nantucket	12	14	90	29.95	29.96	-.02	67.7	-0.1	82	18	74	56	8	62	18	65	63	90	3.50	+0.8	12	10,001	sw.	43	ne.	6	7	11	13	6.2	0.0	0.0
Block Island	26	11	46	29.92	29.95	-.02	69.2	+0.8	81	19	75	59	7	64	20	66	64	90	3.08	0.0	10	9,855	sw.	39	sw.	4	5	13	13	6.2	0.0	0.0
Providence	160	215	251	29.78	29.95	-.02	73.6	+0.2	93	39	82	56	7	65	31	66	63	73	5.00	+1.7	10	6,334	nw.	30	nw.	29	12	8	11	5.3	0.0	0.0
Hartford	159	122	----	29.79	29.96	-.01	74.0	+2.4	95	8	83	54	31	65	32	----	----	----	4.88	+0.5	12	------	sw.	----	------	----	14	6	11	4.6	0.0	0.0
New Haven	106	74	153	29.85	29.96	-.01	74.2	+2.4	92	18	83	55	30	66	29	67	64	75	7.86	+3.5	14	5,415	sw.	36	ne.	24	15	9	7	4.5	0.0	0.0
Middle Atlantic States							75.4	+0.7										76	4.55	+0.2										4.9		
Albany	97	102	115	29.84	29.94	-.02	74.2	+1.6	95	9	83	53	21	65	26	67	64	75	3.99	+0.6	10	4,228	sw.	19	s.	14	15	8	8	4.2	0.0	0.0
Binghamton	871	10	84	29.04	29.95	-.02	72.0	+2.0	93	8	82	46	31	62	36	----	----	----	3.73	+0.2	13	3,073	w.	17	w.	23	10	12	9	5.5	0.0	0.0
New York	314	414	454	29.64	29.96	-.02	75.0	+1.2	92	9	83	61	7	67	27	67	63	72	7.72	+3.5	14	9,181	s.	50	n.	20	6	14	11	5.9	0.0	0.0
Harrisburg	374	94	104	29.59	29.98	.00	75.4	+0.6	94	8	85	56	31	66	25	68	64	72	5.20	+1.3	13	3,339	w.	34	nw.	20	15	8	8	4.6	0.0	0.0
Philadelphia	114	123	341	29.86	29.98	.00	77.4	+1.2	93	20	85	64	29	69	23	70	67	74	3.00	-0.6	11	5,676	sw.	28	ne.	20	12	11	8	5.0	0.0	0.0
Reading	325	81	98	29.62	29.97	------	76.0	------	93	9	85	56	31	66	26	68	65	72	5.04	+0.8	10	3,511	sw.	22	n.	4	14	7	10	5.1	0.0	0.0
Scranton	805	111	119	29.13	29.98	.00	72.8	+1.1	93	9	83	49	30	62	33	66	63	74	8.57	+4.7	14	3,892	s.	23	s.	11	6	12	13	6.1	0.0	0.0
Atlantic City	52	37	172	29.92	29.97	-.01	72.1	0.0	88	28	78	61	7	66	22	68	66	83	3.40	-0.5	11	10,513	sw.	36	ne.	6	15	10	6	3.6	0.0	0.0
Cape May	17	13	49	------	------	------	73.1	-0.3	92	20	80	58	31	66	24	69	67	87	4.99	------	10	------	s.	----	------	----	12	12	7	----	0.0	0.0
Sandy Hook	22	10	55	29.94	29.96	------	74.9	------	90	8	82	63	21	68	25	68	66	80	8.42	------	12	7,732	sw.	41	n.	6	13	7	11	4.8	0.0	0.0
Trenton	190	159	183	29.77	29.97	------	75.4	------	93	9	85	59	30	66	28	69	66	76	7.17	+2.4	14	5,730	sw.	34	w.	4	13	7	11	5.5	0.0	0.0
Baltimore	123	100	215	29.85	29.97	-.01	79.2	+2.0	97	20	88	62	31	70	25	70	66	67	3.54	-1.1	11	5,673	sw.	34	nw.	4	16	8	7	4.5	0.0	0.0
Washington	112	62	85	29.86	29.97	-.03	78.1	+1.3	97	4	88	58	30	69	27	70	66	71	2.17	-2.5	10	3,049	s.	28	nw.	4	13	10	8	5.1	0.0	0.0
Cape Henry	18	8	54	29.97	29.99	------	77.5	------	97	20	85	62	31	70	24	72	70	80	5.94	+0.6	11	5,979	sw.	32	nw.	5	17	7	7	4.2	0.0	0.0
Lynchburg	681	153	188	29.27	30.00	-.01	77.8	+0.3	96	19	88	60	31	67	31	69	66	70	3.55	-0.7	8	3,736	w.	30	n.	20	12	17	2	4.6	0.0	0.0
Norfolk	91	170	205	29.92	30.01	+.01	79.0	+0.3	93	20	87	66	31	71	21	71	68	76	4.41	-1.3	12	7,130	s.	45	sw.	5	13	10	8	4.8	0.0	0.0
Richmond	144	11	52	29.86	30.00	-.01	78.4	-0.1	96	20	88	59	31	69	24	71	68	76	1.95	-2.8	7	4,205	sw.	31	nw.	27	17	11	3	3.6	0.0	0.0
Wytheville	2,304	49	55	27.71	30.01	.00	71.5	-1.1	88	19	82	54	15	61	31	65	63	79	2.83	-1.2	10	2,694	w.	19	sw.	5	7	16	8	5.5	0.0	0.0
South Atlantic States							79.6	+0.5										80	5.32	-0.7										5.6		
Asheville	2,253	70	84	27.72	30.00	-.02	73.0	+1.3	87	21	83	55	1	64	26	66	64	83	3.78	-1.0	13	3,613	se.	27	n.	5	7	17	7	5.5	0.0	0.0
Charlotte	779	55	62	29.20	30.02	.00	80.6	+2.2	97	20	90	64	1	71	26	71	69	75	1.76	-3.3	12	2,203	sw.	21	ne.	5	3	19	9	6.2	0.0	0.0
Hatteras	11	11	50	30.01	30.02	+.01	78.6	+0.4	88	2	84	67	8	73	18	74	72	81	2.17	-3.3	10	7,329	sw.	30	sw.	13	12	11	8	4.6	0.0	0.0
Raleigh	376	103	110	29.62	30.01	-.01	79.4	+0.6	95	21	88	64	31	70	23	72	69	77	2.31	-3.8	9	4,310	sw.	21	s.	4	7	18	6	5.6	0.0	0.0
Wilmington	78	81	91	29.96	30.04	+.03	79.0	-0.1	93	28	86	64	2	72	24	73	72	84	9.57	+2.4	13	4,722	sw.	22	ne.	2	11	11	9	5.5	0.0	0.0
Charleston	48	11	92	29.99	30.04	+.01	81.0	-0.4	94	28	87	70	14	75	21	75	73	81	5.16	-1.7	9	6,317	sw.	27	n.	29	10	10	11	5.7	0.0	0.0
Columbia, S. C.	351	41	57	29.65	30.02	.00	80.8	-0.1	95	23	90	67	1	72	27	72	70	80	9.78	+3.7	16	3,253	s.	19	s.	7	12	11	8	5.1	0.0	0.0
Due West	711	10	55	29.29	30.05	------	79.2	------	96	4	89	63	15	69	27	----	----	----	2.44	------	9	4,235	sw.	29	n.	5	9	14	8	5.5	0.0	0.0
Greenville, S. C.	1,039	139	146	28.95	30.02	------	78.6	+1.7	94	4	88	64	5	69	26	71	68	79	7.58	------	15	3,780	w.	34	w.	5	4	18	9	6.1	0.0	0.0
Augusta	182	62	77	29.82	30.01	-.01	82.0	+0.7	96	4	92	69	6	72	27	73	71	76	3.66	-1.7	11	3,196	s.	32	nw.	5	6	15	10	5.6	0.0	0.0
Savannah	65	150	194	29.97	30.04	+.01	81.2	-0.3	94	29	89	70	17	73	21	74	72	81	6.02	-0.6	13	6,533	sw.	29	nw.	5	9	11	11	5.9	0.0	0.0
Jacksonville	43	209	245	30.00	30.05	+.02	81.5	-0.6	94	27	90	69	3	74	20	74	72	80	8.96	+2.2	13	5,842	sw.	40	s.	1	4	16	11	6.2	0.0	0.0
Florida Peninsula							82.5	+0.6										75	3.31	-2.7										5.8		
Key West	22	10	64	30.01	30.03	.00	83.7	+0.2	92	22	89	73	9	78	16	76	74	74	1.73	-1.6	6	5,275	se.	25	se.	14	13	11	7	4.5	0.0	0.0
Miami	25	71	164	30.04	30.07	------	81.5	+0.5	89	24	87	70	29	76	18	75	73	75	3.65	-2.5	9	5,071	se.	24	se.	11	6	14	11	6.2	0.0	0.0
Tampa	35	79	87	30.02	30.05	+.01	82.4	+1.2	94	28	90	71	20	75	20	75	72	77	4.54	-3.9	13	3,180	e.	15	sw.	12	1	18	12	6.8	0.0	0.0
Titusville	44	5	----	30.01	30.06	------	81.4	------	98	2	91	68	5	72	26	----	----	----	5.65	------	10	------	sw.	----	------	----	9	9	13	5.9	0.0	0.0
East Gulf States							80.9	+0.2										79	5.57	+0.4										5.5		
Atlanta	1,173	190	216	28.83	30.04	+.02	78.8	+0.7	93	4	87	66	6	70	24	70	67	75	8.60	+4.0	14	4,826	nw.	36	nw.	6	7	14	10	6.0	0.0	0.0
Macon	370	78	87	29.64	30.03	+.01	80.7	-0.5	95	5	90	67	1	72	25	74	72	82	5.48	+0.8	14	3,266	s.	24	n.	6	14	10	7	4.6	0.0	0.0
Thomasville	273	49	58	29.75	30.04	+.01	81.1	-0.7	95	30	90	69	7	72	24	74	72	82	10.45	+5.1	19	2,109	sw.	19	n.	6	6	12	13	6.2	0.0	0.0
Apalachicola	36	42	49	30.00	30.04	------	81.2	------	94	29	87	69	2	75	17	76	74	80	4.75	------	14	3,730	sw.	34	ne.	30	10	13	8	5.2	0.0	0.0
Pensacola	56	149	185	29.98	30.04	+.03	81.1	+0.1	92	1	86	72	21	76	17	75	73	79	6.56	-0.2	18	6,482	s.	36	s.	1	6	16	9	6.2	0.0	0.0
Anniston	741	9	57	29.27	30.05	+.03	79.0	+1.1	95	4	90	61	15	69	29	----	----	----	3.82	-0.9	13	1,963	s.	18	nw.	21	8	19	4	4.7	0.0	0.0
Birmingham	700	11	48	29.29	30.04	+.03	79.9	-0.3	94	5	89	66	30	70	24	72	70	79	2.16	-2.5	11	2,847	s.	18	se.	24	8	15	8	5.3	0.0	0.0
Mobile	57	125	161	29.97	30.03	+.02	82.4	+1.0	96	1	90	71	31	75	21	75	73	80	3.33	-3.6	13	4,398	sw.	20	nw.	2	3	22	6	6.0	0.0	0.0
Montgomery	223	100	112	29.79	30.03	+.01	81.5	-0.2	95	4	90	69	6	72	24	73	71	78	3.69	-1.2	12	3,340	sw.	30	ne.	6	6	17	8	5.5	0.0	0.0
Corinth	469	6	----	------	------	------	81.4	------	98	4	91	62	30	72	28	----	----	----	1.78	------	10	------	s.	----	------	----	6	25	0	----	0.0	0.0
Meridian	375	87	95	29.64	30.02	.00	80.8	+0.4	95	5	90	68	15	71	22	74	71	80	8.08	+3.6	10	2,894	sw.	22	nw.	22	10	17	4	4.8	0.0	0.0
Vicksburg	247	65	73	29.76	30.04	+.04	81.2	-0.1	94	4	89	70	17	73	20	74	72	81	3.89	-0.6	11	3,319	w.	23	e.	10	11	12	8	4.9	0.0	0.0
New Orleans	53	76	84	29.97	30.02	+.02	82.9	+0.5	96	3	90	70	22	76	23	76	73	78	5.81	-0.6	17	2,940	w.	26	ne.	3	3	18	10	6.4	0.0	0.0
West Gulf States							82.8	+0.3										74	2.11	-0.8										3.9		
Shreveport	249	77	93	29.75	30.01	+.03	83.4	+0.2	99	4	93	68	23	74	23	74	71	74	3.46	-0.1	8	3,243	s.	17	ne.	12	15	9	7	4.4	0.0	0.0
Bentonville	1,303	11	44	28.64	29.98	+.01	77.2	-1.3	93	20	87	62	14	68	26	----	----	----	3.15	------	12	------	s.	----	w.	----	23	7	1	----	0.0	0.0
Fort Smith	457	79	94	29.50	29.97	.00	81.1	-0.4	99	4	90	66	14	72	24	73	70	73	2.48	-0.9	8	4,048	e.	28	se.	7	16	10	5	4.0	0.0	0.0
Little Rock	357	136	153	29.63	30.00	+.01	81.0	-0.1	95	4	90	68	29	72	25	73	70	72	2.79	-1.2	9	4,279	sw.	24	w.	22	14	7	10	4.7	0.0	0.0
Austin	605	136	148	29.34	29.96	------	84.4	------	99	3	95	70	27	74	25	74	70	69	1.75	-0.6	5	5,012	se.	25	ne.	26	12	17	2	4.1	0.0	0.0
Brownsville	57	53	61	29.89	29.95	------	84.0	+0.4	95	23	92	75	13	76	20	76	74	79	0.71	-1.2	4	5,349	se.	21	se.	26	23	7	1	2.2	0.0	0.0
Corpus Chritsi	20	11	78	29.96	29.98	+.02	83.6	+0.9	92	23	89	74	6	78	14	78	76	83	0.33	-1.3	4	8,559	se.	26	se.	26	14	11	6	4.1	0.0	0.0
Dallas	512	220	227	29.44	29.97	------	82.3	------	97	22	91	69	28	74	21	----	----	----	3.64	------	7	6,678	se.	34	se.	7	17	6	8	4.0	0.0	0.0
Fort Worth	670	106	114	29.25	29.95	-.01	83.1	-0.5	98	4	92	69	9	74	23	73	69	68	4.24	+1.7	6	6,082	s.	25	se.	7	13	12	6	4.5	0.0	0.0
Galveston	54	106	114	29.97	30.02	+.04	83.8	+0.4	91	23	88	72	7	80	15	77	74	77	1.14	-2.6	5	6,754	s.	26	s.	7	18	11	2	3.2	0.0	0.0
Groesbeck	461	11	56	29.50	29.98	------	82.3	------	98	13	92	66	24	72	26	----	----	----	4.03	------	8	6,032	se.	42	sw.	24	17	9	5	3.9	0.0	0.0
Houston	138	202	314	29.86	30.00	------	84.3	+0.6	98	23	93	70	10	76	22	----	----	----	3.43	-0.7	8	6,372	s.	33	ne.	10	15	14	2	4.0	0.0	0.0
Palestine	510	64	72	29.48	30.00	+.03	82.4	+0.2	95	21	91	69	26	73	21	74	71	75	2.81	+0.1	8	4,169	s.	22	s.	6	19	5	7	3.8	0.0	0.0
Port Arthur	34	58	66	29.97	30.01	------	83.3	------	93	17	90	73	18	77	19	76	74	78	5.01	------	13	4,483	s.	22	e.	22	16	10	5	3.9	0.0	0.0
San Antonio	693	119	132	29.24	29.95	.00	85.0	+1.2	100	25	96	71	26	74	25	73	68	64	1.03	-1.1	6	5,042	se.	30	sw.	24	13	14	4	4.2	0.0	0.0
Taylor	583	55	63	29.41	30.02	+.06	84.2	+1.5	100	13	95	70	27	73	27	----	----	----	1.10	-1.5	4	5,704	s.	28	s.	7	16	11	4	3.9	0.0	0.0

TABLE 1.—*Climatological data for Weather Bureau stations, July, 1928*—Continued

District and station	Elevation of instruments: Barometer above sea level	Elevation of instruments: Thermometer above ground	Elevation of instruments: Anemometer above ground	Pressure: Station reduced to mean of 24 hours	Pressure: Sea level, reduced to mean of 24 hours	Pressure: Departure from normal	Temperature of the air: Mean max. + mean min. ÷ 2	Temperature of the air: Departure from normal	Temperature of the air: Maximum	Temperature of the air: Date	Temperature of the air: Mean maximum	Temperature of the air: Minimum	Temperature of the air: Date	Temperature of the air: Mean minimum	Temperature of the air: Greatest daily range	Mean wet thermometer	Mean temperature of the dew point	Mean relative humidity	Precipitation: Total	Precipitation: Departure from normal	Precipitation: Days with 0.01, or more	Wind: Total movement	Wind: Prevailing direction	Wind: Maximum velocity: Miles per hour	Wind: Maximum velocity: Direction	Wind: Maximum velocity: Date	Clear days	Partly cloudy days	Cloudy days	Average cloudiness, tenths	Total snowfall	Snow, sleet, and ice on ground at end of month
	Ft.	Ft.	Ft.	In.	In.	In.	°F.	°F.	°F.		°F.	°F.		°F.	°F.	°F.	°F.	%	In.	In.		Miles.								0-10	In.	In.
Ohio Valley and Tennessee							76.4	-0.1										74	3.72	-0.1										5.0		
Chattanooga	762	190	215	29.21	30.01	-0.01	78.4	0.0	94	4	88	65	3	69	26	71	68	77	6.85	+2.6	15	3,688	sw.	28	ne.	7	4	21	6	5.8	0.0	0.0
Knoxville	995	102	111	28.99	30.02	.00	78.0	+0.9	94	3	88	62	1	68	30	70	67	78	2.56	-1.8	12	3,103	sw.	31	n.	4	5	19	7	6.0	0.0	0.0
Memphis	399	76	97	29.58	30.00	.00	80.8	+0.1	94	4	88	64	30	73	21	73	70	72	1.36	-1.8	6	4,185	sw.	28	sw.	22	14	13	4	4.1	0.0	0.0
Nashville	546	168	191	29.45	30.02	+.01	79.0	-0.1	93	22	88	64	15	70	26	71	78	73	3.62	-0.3	12	4,062	w.	36	n.	7	4	21	6	5.5	0.0	0.0
Lexington	989	193	230	28.98	30.02	+.01	75.8	-0.1	90	21	84	58	29	68	21				5.16	+0.7	10	5,973	sw.	28	sw.	5	20	8	3	3.4	0.0	0.0
Louisville	525	188	234	29.44	30.02	+.02	77.3	-1.3	92	20	86	57	30	69	25	70	66	73	2.17	-1.5	7	4,780	s.	28	n.	4	10	19	2	4.4	0.0	0.0
Evansville	431	76	116	29.56	30.02	+.02	79.5	+0.8	95	21	88	58	29	71	26	71	67	71	1.82	-1.6	6	4,272	s.	40	nw.	6	12	17	2	4.5	0.0	0.0
Indianapolis	822	194	230	29.13	30.00	+.01	75.7	0.0	91	7	85	55	29	67	23	67	63	68	3.07	-0.3	10	5,307	s.	37	w.	4	7	21	3	4.9	0.0	0.0
Royal Center	736	11	55	29.21	30.00	-----	72.1	-----	90	7	83	48	29	62	27				3.54	-----	12	4,556	s.	39	nw.	10	10	14	7	5.2	0.0	0.0
Terre Haute	575	96	129	29.38	29.99	-----	76.7	-----	94	10	86	56	30	67	25	68	64	69	2.45	-----	8	4,597	s.	32	n.	4	9	20	2	4.7	0.0	0.0
Cincinnati	627	11	51	29.34	30.00	.00	75.4	+0.3	93	21	86	53	30	65	27	69	66	74	4.61	+1.8	8	3,172	sw.	33	nw.	11	10	18	3	4.5	0.0	0.0
Columbus	822	179	222	29.15	30.00	.00	75.0	+0.1	92	20	84	58	29	66	23	68	64	73	6.27	+2.7	14	4,497	s.	41	nw.	27	14	14	3	4.2	0.0	0.0
Dayton	899	137	173	29.06	29.99	-----	75.4	0.0	93	21	85	53	30	66	27	67	64	71	2.24	-1.0	7	4,306	sw.	33	w.	20	6	22	3	5.7	0.0	0.0
Elkins	1,947	59	67	28.03	30.02	+.01	69.4	-0.9	90	8	80	46	30	58	32	64	62	84	4.81	+0.2	16	2,421	w.	22	w.	4	6	16	9	6.0	0.0	0.0
Parkersburg	637	77	82	29.38	30.03	+.02	76.0	+0.6	94	20	86	56	30	66	31	68	64	72	2.61	-2.0	10	2,657	se.	22	nw.	20	11	12	8	5.4	0.0	0.0
Pittsburgh	842	353	410	29.10	29.98	-.02	73.4	-1.2	93	8	82	55	29	65	26	67	64	74	4.93	+0.9	11	5,218	sw.	27	w.	9	9	15	7	5.6	0.0	0.0
Lower Lake Region							72.1	+0.6										73	4.03	+0.8										5.0		
Buffalo	767	247	280	29.13	29.95	-.02	69.2	-0.6	87	8	75	53	29	63	20	66	63	82	2.74	-0.3	10	9,154	sw.	50	w.	3	11	11	9	5.3	0.0	0.0
Canton	448	10	61	29.45	29.91	-----	69.0	+1.5	93	9	78	47	26	59	32				3.30	+0.1	16	5,213	sw.	26	sw.	15	18	8	5	3.8	0.0	0.0
Ithaca	836	5	100	29.04	29.93		70.4	-----	92	8	80	46	30	60	35	65	62	77	2.84	-0.7	11	4,741	nw.	22	nw.	29	9	11	11	5.7	0.0	0.0
Oswego	335	76	91	29.57	29.93	-.03	69.6	-0.8	92	9	77	54	31	62	30	64	61	75	3.62	+0.7	11	4,765	w.	20	sw.	3	9	12	10	5.4	0.0	0.0
Rochester	523	86	102	29.40	29.96	-.01	72.0	+1.3	94	8	81	54	31	63	30	64	60	69	3.72	+0.8	8	4,589	sw.	24	sw.	18	11	12	8	4.8	0.0	0.0
Syracuse	597	97	113	29.32	29.96	-.01	71.1	+0.8	92	9	79	54	29	63	27				6.14	+2.5	11	5,809	nw.	26	nw.	28	10	10	11	5.6	0.0	0.0
Erie	714	130	166	29.22	29.96	-.02	72.4	+1.4	90	8	79	56	30	66	24	66	63	73	3.63	+0.6	9	7,056	w.	46	sw.	3	17	7	7	3.8	0.0	0.0
Cleveland	762	190	201	29.17	29.97	-.02	73.1	+1.7	89	8	80	56	29	66	26	65	61	68	6.91	+3.5	12	5,772	sw.	32	w.	27	8	13	10	5.4	0.0	0.0
Sandusky	629	5	67	29.31	29.98	-.01	74.8	+1.4	92	7	84	55	30	65	29				4.04	+0.6	12	4,387	sw.	20	nw.	27	7	18	6	5.2	0.0	0.0
Toledo	628	208	243	29.31	29.98	-.01	74.2	+1.0	91	8	83	55	29	65	25	66	63	70	3.28	+0.3	11	6,874	sw.	42	sw.	19	14	15	2	3.7	0.0	0.0
Fort Wayne	856	113	124	29.07	29.98	-----	74.0	+0.5	91	7	84	51	29	64	27	67	63	74	4.32	-----	12	4,668	sw.	30	sw.	21	6	19	6	5.8	0.0	0.0
Detroit	730	218	258	29.20	29.97	-.01	73.6	+1.5	93	8	83	56	29	64	26	65	61	69	4.07	+0.8	8	5,302	sw.	27	sw.	3	5	18	8	5.8	0.0	0.0
Upper Lake Region							67.9	-0.1										76	2.85	-0.2										4.9		
Alpena	609	13	92	29.29	29.95	-.02	66.8	+0.9	95	8	76	46	30	58	31	62	58	75	1.65	-1.1	12	6,395	nw.	27	nw.	15	11	14	6	5.3	0.0	0.0
Escanaba	612	54	60	29.28	29.94	-0.3	65.4	-0.6	85	3	74	48	29	57	25	60	57	78	4.04	+0.7	12	6,229	s.	32	ne.	24	10	14	7	4.5	0.0	0.0
Grand Haven	632	54	89	29.29	29.96	-.02	68.9	+0.2	89	8	76	49	29	62	24	64	61	77	1.13	-1.5	7	6,140	s.	28	se.	3	14	13	4	4.2	0.0	0.0
Grand Rapids	707	70	87	29.22	29.97	-.01	72.6	+0.3	95	8	82	48	29	63	27	65	61	69	0.81	-2.1	8	3,460	w.	16	w.	3	8	15	8	5.2	0.0	0.0
Houghton	668	64	99	29.22	29.94	-.02	63.9	-1.6	87	16	73	46	28	55	29				3.81	+0.7	13	6,184	w.	48	nw.	7	6	15	10	6.1	0.0	0.0
Lansing	878	6	49	29.04	29.96	-----	70.5	-0.4	91	7	81	46	29	60	29	65	62	77	1.89	-1.2	10	2,741	w.	16	w.	3	16	10	5	4.4	0.0	0.0
Ludington	637	60	66	29.27	29.96	-----	66.4	-----	84	8	73	51	30	60	21	62	60	80	1.84	-----	10	5,876	s.	22	s.	9	17	8	6	3.7	0.0	0.0
Marquette	734	77	111	29.16	29.95	-.01	63.4	-1.5	88	16	72	48	19	55	28	60	58	84	2.63	-0.5	12	5,138	nw.	31	sw.	31	6	14	11	6.0	0.0	0.0
Port Huron	638	70	120	29.27	29.96	-.02	70.2	+1.4	89	8	79	53	29	62	26	64	61	75	2.64	-0.2	9	5,906	sw.	24	nw.	14	13	14	4	4.1	0.0	0.0
Sault Ste. Marie	614	11	52	29.26	29.94	-.03	63.0	-0.8	91	8	72	43	30	54	33	58	55	79	3.46	+0.7	13	4,557	w.	38	nw.	7	8	14	9	5.4	0.0	0.0
Chicago	673	7	131	29.27	29.99	+.01	72.8	+0.3	92	7	80	55	29	65	21	66	63	74	2.95	-0.4	10	5,467	s.	33	nw.	19	12	10	9	4.8	0.0	0.0
Green Bay	617	109	141	29.29	29.95	-.02	69.8	-0.2	91	8	79	50	29	61	26	64	60	74	3.46	0.0	11	6,229	s.	34	s.	2	12	10	9	5.0	0.0	0.0
Milwaukee	681	125	221	29.25	29.98	+.01	71.8	+1.7	94	7	80	54	28	63	29	64	60	70	1.47	-1.4	9	7,008	w.	35	sw.	2	14	9	8	4.7	0.0	0.0
Duluth	1,133	5	47	28.75	29.95	.00	63.0	-0.9	85	16	73	46	28	53	30	59	56	82	7.08	+3.3	12	6,742	ne.	32	nw.	7	13	12	6	4.6	0.0	0.0
North Dakota							68.0	-0.6										74	5.39	+2.6										4.4		
Moorhead	940	50	58	28.93	29.92	-.02	69.3	+1.2	89	25	79	51	29	59	30	63	60	74	7.17	+3.7	10	4,571	n.	46	nw.	1	12	13	6	4.9	0.0	0.0
Bismarck	1,674	8	57	28.18	29.93	.00	69.4	-0.4	92	5	80	47	28	58	29	62	59	73	5.06	+2.8	10	4,797	n.	44	nw.	6	18	7	6	4.2	0.0	0.0
Devils Lake	1,478	11	44	28.39	29.93	.00	66.0	-1.4	89	30	77	45	29	55	32	60	57	77	3.27	-0.5	12	4,786	nw.	35	nw.	6	13	9	9	4.7	0.0	0.0
Ellendale	1,457	10	56	28.40	29.93	-----	69.2	-----	89	30	80	48	28	58	29				4.92	-----	14	6,909	nw.	53	ne.	7	12	16	3	4.5	0.0	0.0
Grand Forks	833	12	67	-----	-----	-----	68.0	-----	87	15	78	48	29	58	31	63	-----	-----	4.68	-----	11	-----	nw.	-----	ne.	11	10	16	5	4.6	0.0	0.0
Williston	1,878	41	48	27.99	29.93	+.01	67.3	-1.6	90	14	78	48	28	56	29	60	56	70	6.07	+4.2	15	3,822	ne.	44	w.	5	16	12	3	3.7	0.0	0.0
Upper Mississippi Valley							75.4	+0.4										72	3.91	+0.4										4.8		
Minneapolis	918	102	208	28.96	29.92	-----	72.3	0.0	94	7	82	54	29	63	26	-----	-----	-----	3.68	0.0	11	6,129	s.	34	nw.	2	7	17	7	5.6	0.0	0.0
St. Paul	837	236	261	29.04	29.93	-.02	71.7	-0.4	91	7	82	53	28	62	25	-----	-----	-----	3.63	+0.1	8	6,263	sw.	33	se.	6	11	14	6	5.0	0.0	0.0
La Crosse	714	11	48	29.19	29.94	-.02	72.7	-0.1	92	7	83	50	28	63	30	66	63	77	6.14	+2.2	11	2,128	s.	21	ne.	2	14	5	12	4.9	0.0	0.0
Madison	974	70	78	28.95	29.97	.00	71.9	-0.2	90	7	80	54	28	64	23	65	62	73	2.64	-1.2	7	4,311	sw.	19	nw.	2	10	11	10	5.5	0.0	0.0
Wausau	1,247	4	-----	28.65	29.96	-----	69.4	-----	90	7	79	47	29	60	30	-----	-----	-----	3.69	-----	10	-----	nw.	-----	-----	-----	9	8	14	6.1	0.0	0.0
Charles City	1,015	10	51	28.91	29.96	.00	72.8	+0.5	92	6	83	49	28	62	28	66	63	73	3.94	+0.4	10	3,226	se.	18	s.	2	16	11	4	3.3	0.0	0.0
Davenport	606	71	79	29.32	29.97	.00	76.0	+0.7	94	7	86	54	28	66	26	68	65	70	4.57	+1.2	9	3,174	s.	22	w.	8	14	9	8	4.7	0.0	0.0
Des Moines	861	84	97	29.06	29.95	-.01	75.4	0.0	95	6	85	57	30	65	27	68	64	73	5.68	+2.2	14	3,925	s.	23	sw.	7	12	13	6	4.9	0.0	0.0
Dubuque	700	81	96	29.23	29.96	-.01	73.6	-0.5	92	7	83	51	29	64	26	66	63	72	3.22	-0.7	11	3,482	s.	21	nw.	19	9	11	11	5.8	0.0	0.0
Keokuk	614	64	78	29.32	29.98	.00	77.4	+0.5	96	6	87	56	28	68	28	69	65	68	2.93	-0.5	7	3,800	s.	27	sw.	19	13	7	11	4.9	0.0	0.0
Cairo	358	87	93	29.63	30.00	.00	80.2	+0.6	94	4	88	62	29	72	21	72	69	72	1.43	-1.6	6	3,903	sw.	27	nw.	31	8	17	6	5.3	0.0	0.0
Peoria	609	11	45	29.34	30.00	+.02	75.6	+0.2	95	7	86	51	29	65	29	69	66	74	4.35	+0.8	9	2,782	s.	26	nw.	3	18	9	4	3.1	0.0	0.0
Springfield, Ill	636	10	91	29.31	29.97	-.01	77.8	+1.3	95	3	87	57	30	69	26	70	66	71	3.09	+0.2	8	4,262	s.	24	sw.	10	16	12	3	4.1	0.0	0.0
Hannibal	534	74	109	29.41	29.97	-.01	77.8	+1.0	95	19	87	59	30	68	26	-----	-----	-----	2.76	-1.0	8	4,524	sw.	35	se.	10	13	10	8	4.5	0.0	0.0
St. Louis	568	265	303	29.39	29.98	-.01	79.9	+1.3	95	3	88	63	29	71	26	70	66	67	6.66	+3.7	4	6,305	sw.	34	e.	5	12	15	4	4.4	0.0	0.0
Missouri Valley							76.2	+0.3										68	3.58	-0.3										4.2		
Columbia, Mo	784	6	84	29.16	29.97	-.01	77.2	+0.3	94	5	86	58	30	68	28	-----	-----	-----	3.72	+0.1	7	3,789	s.	23	s.	11	15	8	8	4.5	0.0	0.0
Kansas City	963	161	181	28.95	29.95	-.02	78.4	+0.3	95	5	87	61	28	70	29	70	66	27	2.64	-1.5	11	5,453	s.	32	ne.	10	15	11	5	4.1	0.0	0.0
St. Joseph	967	11	49	28.94	29.94	-----	77.6	-----	96	5	87	58	28	68	29	70	66	72	3.19	-----	12	4,321	se.	34	se.	10	16	9	6	4.2	0.0	0.0
Springfield, Mo	1,324	98	104	28.64	30.01	+.03	76.6	-0.2	92	20	85	59	29	68	22	69	66	70	3.01	-1.8	5	5,617	s.	30	sw.	11	22	9	0	2.1	0.0	0.0
Iola	984	11	50	28.94	29.96	-.01	79.0	+0.8	95	5	89	60	28	69	30	-----	-----	-----	3.31	-1.1	7	3,279	s.	19	ne.	11	16	9	6	4.2	0.0	0.0
Topeka	987	92	107	-----	-----	-----	78.3	+0.5	98	4	88	60	30	69	25	-----	-----	-----	2.75	-2.1	9	5,330	sw.	44	se.	10	15	10	6	4.2	0.0	0.0
Lincoln	1,189	11	81	28.72	29.93	-.02	77.0	+0.5	101	6	87	57	28	67	30	68	64	69	5.72	+1.9	13	5,223	s.	58	w.	4	8	12	11	5.6	0.0	0.0
Omaha	1,105	115	122	28.79	29.94	-.01	77.1	+0.4	99	6	86	58	28	68	28	68	64	67	6.55	+3.0	7	4,024	se.	32	sw.	4	13	16	2	4.1	0.0	0.0
Valentine	2,598	47	54	27.30	29.96	+.03	72.8	-0.9	94	1	84	53	9	61	39	63	58	66	3.76	+0.4	15	5,257	s.	30	sw.	3	11	15	5	4.7	0.0	0.0
Sioux City	1,135	94	164	28.77	29.95	.00	75.3	+1.0	98	6	86	53	28	65	27	66	62	66	3.83	+0.2	2	6,262	s.	33	n.	21	8	17	6	5.0	0.0	0.0
Huron	1,306	59	74	28.57	29.94	.00	72.4	+0.6	91	16	83	52	28	62	32	65	61	70	2.28	-0.9	10	5,263	s.	45	w.	1	16	14	1	3.7	0.0	0.0
Pierre	1,572	70	75	-----	29.92	-.01	75.0	-0.3	97	30	86	56	27	63	35	-----	-----	64	3.22	-0.9	11	5,576	e.	33	s.	7	18	10	3	-----	0.0	0.0
Yankton	1,233	49	57	28.64	29.92	-.02	74.7	+0.5	101	6	85	57	27	64	29	-----	-----	-----	2.22	-1.2	4	4,080	s.	18	se.	5	10	18	3	4.6	0.0	0.0

TABLE 1.—*Climatological data for Weather Bureau stations, July, 1928*—Continued

District and station	Elevation of instruments: Barometer above sea level	Elevation of instruments: Thermometer above ground	Elevation of instruments: Anemometer above ground	Pressure: Station reduced to mean of 24 hours	Pressure: Sea level, reduced to mean of 24 hours	Pressure: Departure from normal	Temperature of the air: Mean max. + mean min. ÷ 2	Temperature of the air: Departure from normal	Temperature of the air: Maximum	Temperature of the air: Date	Temperature of the air: Mean maximum	Temperature of the air: Minimum	Temperature of the air: Date	Temperature of the air: Mean minimum	Temperature of the air: Greatest daily range	Mean wet thermometer	Mean temperature of the dew point	Mean relative humidity	Precipitation: Total	Precipitation: Departure from normal	Precipitation: Days with 0.01, or more	Wind: Total movement	Wind: Prevailing direction	Wind: Maximum velocity: Miles per hour	Wind: Maximum velocity: Direction	Wind: Maximum velocity: Date	Clear days	Partly cloudy days	Cloudy days	Average cloudiness, tenths	Total snowfall	Snow, sleet, and ice on ground at end of month
	Ft.	Ft.	Ft.	In.	In.	In.	°F.	°F.	°F.		°F.	°F.		°F.	°F.	°F.	°F.	%	In.	In.		Miles								0-10	In.	In.
Northern slope							68.0	+0.1										63	2.31	+0.7										4.4		
Billings	3,140	5	......	......	......	......	69.6	......	97	25	85	44	2	54	43	......	......	......	2.27	......	10	......	nw.	......	......	......	11	14	6	......	0.0	0.0
Havre	2,505	11	44	27.34	29.93	+0.02	69.5	+1.2	95	12	82	48	3	56	38	60	54	63	1.44	-0.4	9	3,917	e.	28	nw.	10	12	14	5	4.2	0.0	0.0
Helena	4,110	87	112	25.83	29.94	+.01	67.0	+1.3	95	26	80	47	4	54	34	56	49	60	1.65	+0.6	9	4,948	sw.	35	sw.	20	8	18	5	5.1	0.0	0.0
Kalispell	2,973	48	56	26.92	29.92	-.01	65.6	+1.5	92	26	78	45	5	53	35	56	50	64	1.49	+0.6	11	3,479	nw.	16	w.	3	16	13	2	3.8	0.0	0.0
Miles City	2,371	48	55	27.46	29.96	+.04	71.8	-1.1	95	15	84	52	3	60	31	61	55	62	4.78	+3.4	8	3,234	s.	47	w.	7	18	9	4	3.5	0.0	0.0
Rapid City	3,259	50	58	26.63	29.97	+.04	69.9	-1.1	92	5	81	53	12	59	31	61	56	64	2.80	+0.2	14	4,063	w.	36	ne.	26	15	12	4	4.1	0.0	0.0
Cheyenne	6,088	84	101	24.11	29.94	+.02	65.8	-0.9	90	31	79	45	8	53	38	54	47	58	1.95	-0.2	10	6,055	s.	37	w.	7	13	11	7	4.5	0.0	0.0
Lander	5,372	60	68	24.72	29.94	+.02	68.0	+0.6	93	30	84	43	2	52	42	55	48	55	0.37	-0.5	7	3,365	sw.	32	sw.	31	14	15	2	4.3	0.0	0.0
Sheridan	3,790	10	47	26.13	29.96	......	67.0	......	92	26	81	43	2	53	40	59	54	70	2.97	......	11	2,463	nw.	21	nw.	9	14	10	7	4.7	0.0	0.0
Yellowstone Park	6,241	11	48	23.99	29.99	+.07	60.6	-0.9	86	26	75	40	21	46	37	49	43	61	1.30	+0.1	13	4,202	sw.	25	nw.	9	8	16	7	5.1	0.0	0.0
North Platte	2,821	11	51	27.08	29.94	+.01	73.4	+0.5	98	6	84	55	8	63	40	65	61	71	5.04	+2.3	14	3,210	s.	24	ne.	11	16	8	7	4.3	0.0	0.0
Middle slope							76.8	-0.4										64	2.96	0.0										4.4		
Denver	5,292	106	113	24.81	29.95	-.04	71.0	-1.2	95	5	84	52	8	58	37	57	47	50	1.01	-0.7	9	4,486	s.	32	n.	28	13	12	6	4.5	0.0	0.0
Pueblo	4,685	80	86	25.34	29.93	+.02	74.0	-0.2	98	5	88	52	8	60	41	58	48	52	1.06	-0.9	7	4,146	n.	25	w.	28	12	17	2	4.4	0.0	0.0
Concordia	1,392	50	58	28.52	29.95	.00	77.2	-0.8	98	5	87	59	28	67	30	69	66	72	7.03	+3.2	15	4,105	s.	29	nw.	11	9	11	11	5.7	0.0	0.0
Dodge City	2,509	11	51	27.41	29.95	+.02	78.1	-0.3	100	3	90	60	8	66	35	66	61	65	2.34	-0.8	10	5,357	se.	29	se.	11	19	8	4	3.2	0.0	0.0
Wichita	1,358	139	158	28.54	29.93	+.03	79.3	-0.1	98	4	89	62	8	69	30	70	66	70	3.46	-0.2	10	7,541	s.	42	nw.	18	16	10	5	3.7	0.0	0.0
Broken Arrow	765	11	56	29.16	29.98	......	79.1	......	93	4	88	65	20	71	24	......	......	......	2.80	......	11	7,071	s.	32	w.	21	12	10	9	4.8	0.0	0.0
Oklahoma City	1,214	10	47	28.70	29.95	-.01	80.9	+0.3	98	4	90	66	8	71	26	71	68	72	2.86	-0.8	9	5,729	s.	19	n.	11	14	12	5	4.4	0.0	0.0
Southern slope							81.7	+0.5										56	2.69	+0.2										4.1		
Abilene	1,738	10	52	28.17	29.92	-.01	84.0	+1.2	103	3	94	65	27	74	27	70	63	59	3.05	+0.9	9	6,274	s.	27	s.	25	11	10	10	5.0	0.0	0.0
Amarillo	3,676	10	49	26.29	29.92	.00	77.7	+0.9	101	4	90	59	8	66	32	64	58	60	5.39	+2.2	9	5,694	s.	24	nw.	13	16	10	5	3.8	0.0	0.0
Del Rio	944	64	71	28.92	29.88	-.02	86.2	-0.1	100	3	95	70	28	77	22	71	64	54	1.38	-0.9	3	7,069	se.	27	s.	30	13	11	7	4.3	0.0	0.0
Roswell	3,566	75	85	26.37	29.88	.00	79.0	+0.1	102	1	92	62	24	66	33	63	54	51	0.95	-1.2	10	5,182	s.	27	sw.	3	19	12	0	3.2	0.0	0.0
Southern Plateau							80.2	+1.3										41	0.38	-0.8										2.6		
El Paso	3,778	152	175	26.16	29.82	-.02	83.6	+2.5	103	3	95	63	19	72	31	63	50	39	1.15	-0.8	4	6,347	e.	34	nw.	20	17	13	1	3.6	0.0	0.0
Santa Fe	7,013	38	53	23.37	29.87	-.01	69.8	+0.8	89	4	82	52	25	57	33	53	42	46	0.65	-1.7	11	3,847	e.	19	ne.	10	8	18	5	4.8	0.0	0.0
Flagstaff	6,907	10	59	23.46	29.87	+.04	66.1	+1.1	86	26	82	41	1	50	43	51	41	50	2.30	......	11	......	nw.	......	......	......	10	15	6	......	0.0	0.0
Phoenix	1,108	10	82	28.64	29.74	-.04	91.8	+2.0	112	24	105	69	1	78	35	67	52	31	0.11	-1.0	2	3,790	w.	23	n.	30	17	14	0	3.0	0.0	0.0
Yuma	141	9	54	29.60	29.74	-.02	91.0	+0.2	116	24	107	63	2	75	41	70	58	41	0.00	-0.2	0	3,472	sw.	22	se.	30	30	1	0	0.6	0.0	0.0
Independence	3,957	6	27	25.91	29.84	+.01	79.2	+1.1	102	24	96	53	3	62	40	54	......	......	0.00	-0.1	0	......	nw.	......	......	......	23	7	1	1.2	0.0	0.0
Middle Plateau							74.3	+1.9										31	0.46	-0.1										2.4		
Reno	4,532	74	81	25.46	29.86	-.01	72.5	+5.0	102	24	90	45	7	55	44	53	39	37	0.16	-0.1	3	4,868	w.	30	w.	31	23	8	0	1.8	0.0	0.0
Tonopah	6,090	12	20	......	......	......	75.2	......	95	28	87	44	1	63	31	51	31	22	0.02	......	1	......	se.	......	......	......	......	......	......	......	......	......
Winnemucca	4,344	18	56	25.60	29.89	-.01	72.5	+1.9	102	26	90	44	19	54	49	52	35	32	0.29	+0.1	2	3,703	sw.	30	s.	15	26	5	0	2.2	0.0	0.0
Modena	5,473	10	43	24.64	29.86	.00	70.8	+0.2	96	27	89	42	2	53	46	51	35	35	1.05	-0.2	3	7,322	sw.	33	s.	12	21	10	0	2.2	0.0	0.0
Salt Lake City	4,360	163	203	25.60	29.87	-.03	77.4	+1.7	100	27	89	51	7	66	36	56	40	30	0.38	-0.1	4	5,593	s.	37	w.	15	21	8	2	2.8	0.0	0.0
Grand Junction	4,602	60	68	25.39	29.89	.00	78.2	+0.5	97	5	92	54	7	64	35	56	39	32	0.41	-0.1	7	4,604	se.	30	nw.	22	17	12	2	3.0	0.0	0.0
Northern Plateau							74.4	+3.3										41	0.60	+0.2										3.3		
Baker	3,471	48	53	26.44	26.96	+.01	68.0	+2.4	101	26	84	41	19	52	41	53	42	46	0.45	0.0	7	3,773	se.	27	se.	28	18	10	3	3.4	0.0	0.0
Boise	2,739	78	86	27.10	29.88	-.05	75.7	+2.8	105	25	91	48	6	60	38	58	45	41	0.13	-0.1	2	3,413	w.	25	ne.	15	22	7	2	2.7	0.0	0.0
Lewiston	757	40	48	29.10	29.89	-.06	77.6	+3.6	113	26	93	55	6	62	46	......	......	......	0.88	+0.5	7	2,030	e.	20	nw.	29	17	8	6	3.5	0.0	0.0
Pocatello	4,477	60	68	25.47	29.87	-.05	73.0	+2.2	97	26	88	42	7	58	40	54	40	37	0.29	-0.3	4	4,752	se.	30	sw.	17	12	15	4	4.2	0.0	0.0
Spokane	1,929	101	110	27.90	29.90	-.06	73.6	+4.6	108	26	87	50	1	60	40	57	45	46	1.26	+0.6	5	3,600	s.	22	n.	18	17	11	3	3.5	0.0	0.0
Walla Walla	991	57	65	28.84	29.89	-.08	78.2	+4.2	112	25	92	56	1	65	39	59	45	37	0.58	+0.2	6	2,805	w.	16	w.	2	20	9	2	2.4	0.0	0.0
North Pacific Coast Region							63.6	+1.6										68	0.45	-0.3										4.9		
North Head	211	11	56	29.80	30.02	-.06	57.6	+0.4	64	5	61	52	13	54	9	55	54	89	0.77	+0.1	8	9,560	n.	37	n.	12	4	4	23	8.1	0.0	0.0
Port Angeles	29	8	53	......	30.06	......	60.5	......	88	25	69	44	15	52	31	......	......	......	0.50	+0.1	3	4,243	nw.	22	w.	11	16	11	4	......	0.0	0.0
Seattle	125	215	250	29.89	30.02	-.02	65.0	+1.9	89	24	74	52	14	56	28	58	53	69	0.11	-0.5	2	4,447	nw.	16	s.	4	10	12	9	5.1	0.0	0.0
Tacoma	194	172	201	29.84	30.04	-.02	65.1	+2.3	91	26	74	51	13	56	29	......	......	......	0.51	-0.1	4	4,638	n.	21	sw.	11	11	10	10	5.6	0.0	0.0
Tatoosh Island	86	9	53	29.95	30.04	-.01	55.9	+0.8	71	25	59	49	15	53	16	54	53	92	0.71	-1.1	9	6,089	s.	28	s.	26	7	8	16	6.6	0.0	0.0
Yakima	1,071	5	......	......	......	......	76.2	......	111	26	92	52	2	60	52	60	......	50	0.13	......	2	......	nw.	......	......	......	20	11	0	2.8	0.0	0.0
Medford	1,425	4	80	28.44	29.91	......	71.8	......	106	22	91	45	6	53	50	58	49	53	T.	......	0	......	nw.	20	n.	31	23	5	3	2.0	0.0	0.0
Portland, Oreg.	153	68	106	29.85	30.01	-.04	69.0	+2.3	99	24	79	50	2	59	32	60	54	64	0.42	-0.2	4	3,836	nw.	16	nw.	11	13	8	10	5.0	0.0	0.0
Roseburg	510	75	99	29.44	29.98	-.05	69.2	+1.8	103	24	83	49	6	56	41	58	50	59	0.12	-0.2	1	3,272	n.	17	ne.	20	14	13	4	3.8	0.0	0.0
Middle Pacific Coast Region							67.1	+0.1										68	T.	0.0										3.1		
Eureka	62	73	89	29.96	30.03	-.02	56.2	+0.7	65	4	60	48	23	53	11	54	52	88	0.02	-0.1	2	4,258	nw.	20	n.	5	2	17	12	7.0	0.0	0.0
Red Bluff	330	54	58	29.48	29.82	-.07	81.6	+0.8	106	30	99	53	3	64	45	64	52	43	0.00	0.0	0	3,377	s.	16	nw.	6	29	2	0	0.7	0.0	0.0
Sacramento	69	106	117	29.77	29.84	-.04	73.0	-0.2	102	7	90	52	10	56	41	61	54	60	T.	0.0	0	6,161	s.	22	sw.	2	28	3	0	0.8	0.0	0.0
San Francisco	155	208	243	29.76	29.93	-.02	58.6	+0.1	75	7	64	50	17	53	21	54	52	83	T.	0.0	0	5,588	sw.	25	w.	6	10	14	7	4.9	0.0	0.0
San Jose	141	12	110	29.78	29.93	......	66.1	-0.8	94	7	79	48	17	53	39	......	......	......	0.00	0.0	0	4,433	nw.	19	se.	20	23	8	0	2.3	0.0	0.0
South Pacific Coast Region							72.4	-0.8										62	T.	0.0										2.4		
Fresno	327	89	98	29.49	29.83	.00	81.3	-0.8	108	30	98	54	1	64	39	60	44	34	0.00	0.0	0	5,350	nw.	21	nw.	8	26	5	0	1.0	0.0	0.0
Los Angeles	338	159	191	29.55	29.91	+.01	69.2	-1.0	85	31	79	56	13	60	24	61	57	71	0.00	0.0	0	3,322	sw.	13	sw.	1	22	9	0	2.8	0.0	0.0
San Diego	87	62	70	29.82	29.91	-.01	66.6	-0.6	78	31	71	59	6	62	16	62	59	81	T.	0.0	0	4,158	w.	17	s.	30	20	10	1	3.5	0.0	0.0
West Indies																																
San Juan, P. R.	82	9	54	29.94	30.03	......	80.0	-0.1	90	26	85	70	9	75	15	......	......	......	8.58	-2.2	19	9,488	e.	32	e.	9	2	25	4	5.6	0.0	0.0
Panama Canal																																
Balboa Heights	118	7	97	[1]29.72	[1]29.81	-.03	81.0	+0.7	92	15	87	70	7	75	17	......	......	......	7.91	+0.6	16	......	nw.	......	s.	28	0	13	18	7.8	0.0	0.0
Colon	38	7	97	[1]29.80	[1]29.82	-.04	82.2	+1.8	91	22	87	73	7	77	15	......	......	......	10.29	-5.4	19	......	n.	......	n.	16	0	5	26	8.6	0.0	0.0
Alaska																																
Juneau	80	11	54	[2]29.94	[2]30.02	......	56.3	......	85	3	63	44	24	50	34	52	48	78	4.61	......	13	4,432	se.	24	nw.	25	9	0	22	7.1	0.0	0.0
Hawaiian Islands																																
Honolulu	38	86	100	[2]29.99	[2]30.03	......	77.5	......	84	22	82	71	17	74	10	69	66	69	1.41	+0.2	10	7,478	e.	29	ne.	26	13	14	4	4.4	0.0	0.0

[1] Observations taken bi-hourly.

[2] Pressure not corrected to mean of 24 hours.

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TABLE 2.—*Data furnished by the Canadian Meteorological Service, July, 1928*

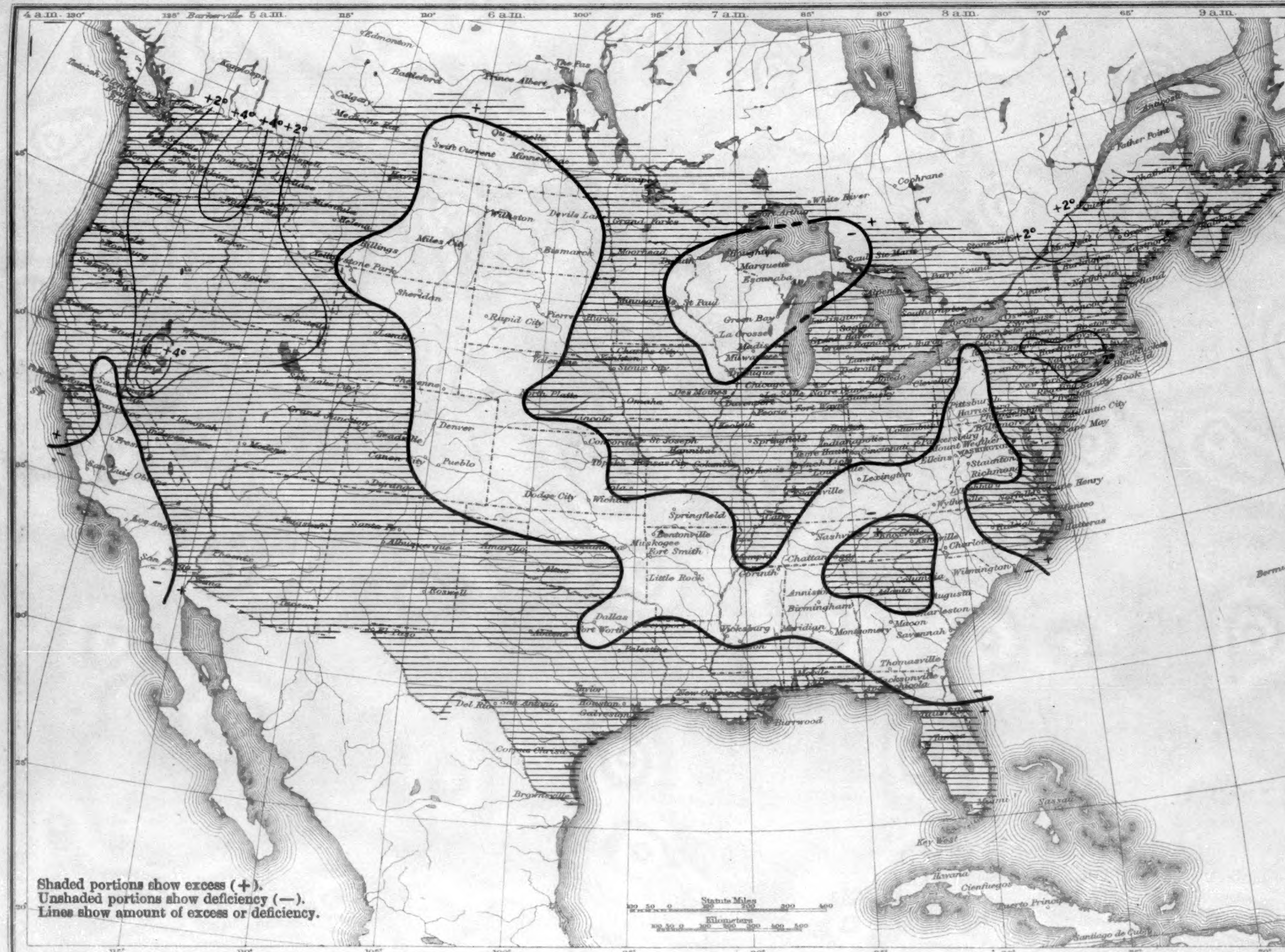
Station	Altitude above mean sea level, Jan. 1, 1919	Pressure: Station reduced to mean of 24 hours	Pressure: Sea level reduced to mean of 24 hours	Pressure: Departure from normal	Temperature of the air: Mean max. + mean min. ÷ 2	Temperature of the air: Departure from normal	Temperature of the air: Mean maximum	Temperature of the air: Mean minimum	Temperature of the air: Highest	Temperature of the air: Lowest	Precipitation: Total	Precipitation: Departure from normal	Precipitation: Total snowfall
	Feet	*Inches*	*Inches*	*Inches*	*° F.*	*° F.*	*° F.*	*° F.*	*° F.*	*° F.*	*Inches*	*Inches*	*Inches*
Cape Race, N. F	99												
Sydney, C. B. I	48												
Halifax, N. S	88												
Yarmouth, N. S	65												
Charlottetown, P. E. I	38												
Chatham, N. B	28												
Father Point, Que	20												
Quebec, Que	296	29.60	29.92	+0.01	67.1	+1.6	75.4	58.8	85	48	4.82	+0.56	0.0
Doucet, Que	1,236				63.0		70.9	55.2	82	36	6.68		0.0
Montreal, Que	187	29.68	29.88	−.05	70.9	+2.4	79.4	62.3	87	53	3.89	−0.40	0.0
Ottawa, Ont	236												
Kingston, Ont	285	29.62	29.92	−.05	68.2	0.0	75.2	61.2	85	51	2.68	−0.21	0.0
Toronto, Ont	379	29.54	29.93	−.04	69.9	+1.9	79.4	60.4	90	52	5.64	+2.72	0.0
Cochrane, Ont	930				62.3		72.1	52.5	86	38	2.49		0.0
White River, Ont	1,244	28.60	29.89	−.05	60.9	+1.4	72.2	49.5	85	34	4.59	+1.79	0.0
London, Ont	808				70.3		80.7	60.0	91	48	3.00		0.0
Southampton, Ont	656	29.24	29.95	−.02	65.6	+0.9	74.6	56.6	89	46	5.70	+3.72	0.0
Parry Sound, Ont	688	29.24	29.92	−.04	66.9	+0.9	75.0	58.8	86	48	4.67	+2.05	0.0
Port Arthur, Ont	644	29.25	29.96	+.02	62.7	+0.7	71.9	53.6	90	42	3.46	−0.02	0.0
Winnipeg, Man	760												
Minnedosa, Man	1,690	28.16	29.94	+.01	63.8	+1.6	73.2	54.4	85	43	3.42	+0.82	0.0
Le Pas, Man	860				63.6		75.2	52.0	86	40	2.60		0.0
Qu' Appelle, Sask	2,115												
Moose Jaw, Sask	1,759				65.8		78.5	53.2	92	42	1.58		0.0
Swift Current, Sask	2,392	27.43	29.90	−.01	65.6	−0.9	78.0	53.3	90	43	2.78	+0.34	0.0
Medicine Hat, Alb	2,144												
Calgary, Alb	3,428												
Banff, Alb	4,521												
Prince Albert, Sask	1,450	28.41	29.96	+.05	65.1	+3.2	76.7	53.6	90	43	1.50	−0.55	0.0
Battleford, Sask	1,592	28.22	29.93	+.03	65.3	+0.6	77.1	53.5	90	46	2.39	+0.05	0.0
Edmonton, Alb	2,150												
Kamloops, B. C	1,262												
Victoria, B. C	230												
Barkerville, B. C	4,180												
Estevan Point, B. C	20												
Prince Rupert, B. C	170												
Hamilton, Ber	151												

LATE REPORTS, JUNE, 1928

Station	Altitude	Station pressure	Sea level pressure	Pressure departure	Mean temp.	Temp. departure	Mean max.	Mean min.	Highest	Lowest	Precip. total	Precip. departure	Total snowfall
Cape Race, N. F	99				48.5		56.0	41.0	68	36	1.62		0.0
Father Point, Que	20	29.81	29.83	−0.04	54.1	+1.1	62.6	45.6	78	38	2.60	−0.38	0.0
Kingston, Ont	285	29.55	29.86	−.11	59.8	−3.6	66.2	53.4	78	42	4.12	+1.69	0.0
London, Ont	808				61.7		71.0	52.4	82	34	4.94		0.0
Southampton, Ont	656	29.14	29.85	−.12	58.4	−2.0	69.3	47.5	84	35	3.83	+1.48	0.0
Winnipeg, Man	760	29.02	29.84	−.05	59.4	−2.8	69.6	49.3	84	34	3.58	+0.29	0.0
Medicine Hat, Alb	2,144	27.52	29.75	−.10	59.3	−2.7	70.5	48.2	86	36	3.58	+0.82	0.0
Calgary, Alb	3,428	26.35	29.88	+.04	54.5	−1.5	65.9	43.2	81	30	8.45	+6.00	0.0
Banff, Alb	4,521	25.33	29.85	+.01	50.9	−0.6	62.2	39.7	81	27	6.05	+2.72	1.9
Kamloops, B. C	1,262	28.57	29.84	−.03	65.4	+1.6	75.7	55.1	92	43	1.55	+0.13	0.0
Barkerville, B. C	4,180	25.62	29.88	+.01	51.7	+1.0	62.6	40.8	77	27	5.72	+2.24	0.0
Estevan Point, B. C	20				54.4		60.2	48.6	67	41	1.47		0.0
Prince Rupert, B. C	170				55.1		63.6	46.6	76	40	1.71		0.0
Hamilton, Ber	151	29.98	30.14	+.02	75.6	+0.6	82.5	68.8	88	65	2.02	−3.93	0.0

Chart I. Departure (°F.) of the Mean Temperature from the Normal, July, 1928

Chart I. Departure (°F.) of the Mean Temperature from the Normal, July, 1928



Shaded portions show excess (+).
Unshaded portions show deficiency (—).
Lines show amount of excess or deficiency.

Chart II. Tracks of Centers of Anticyclones, July, 1928. (Inset) Departure of Monthly Mean Pressure from Normal

(Plotted by Wilfred P. Day)

Chart III. Tracks of Centers of Cyclones, July, 1928. (Inset) Change in Mean Pressure from Preceding Month

(Plotted by Wilfred P. Day)

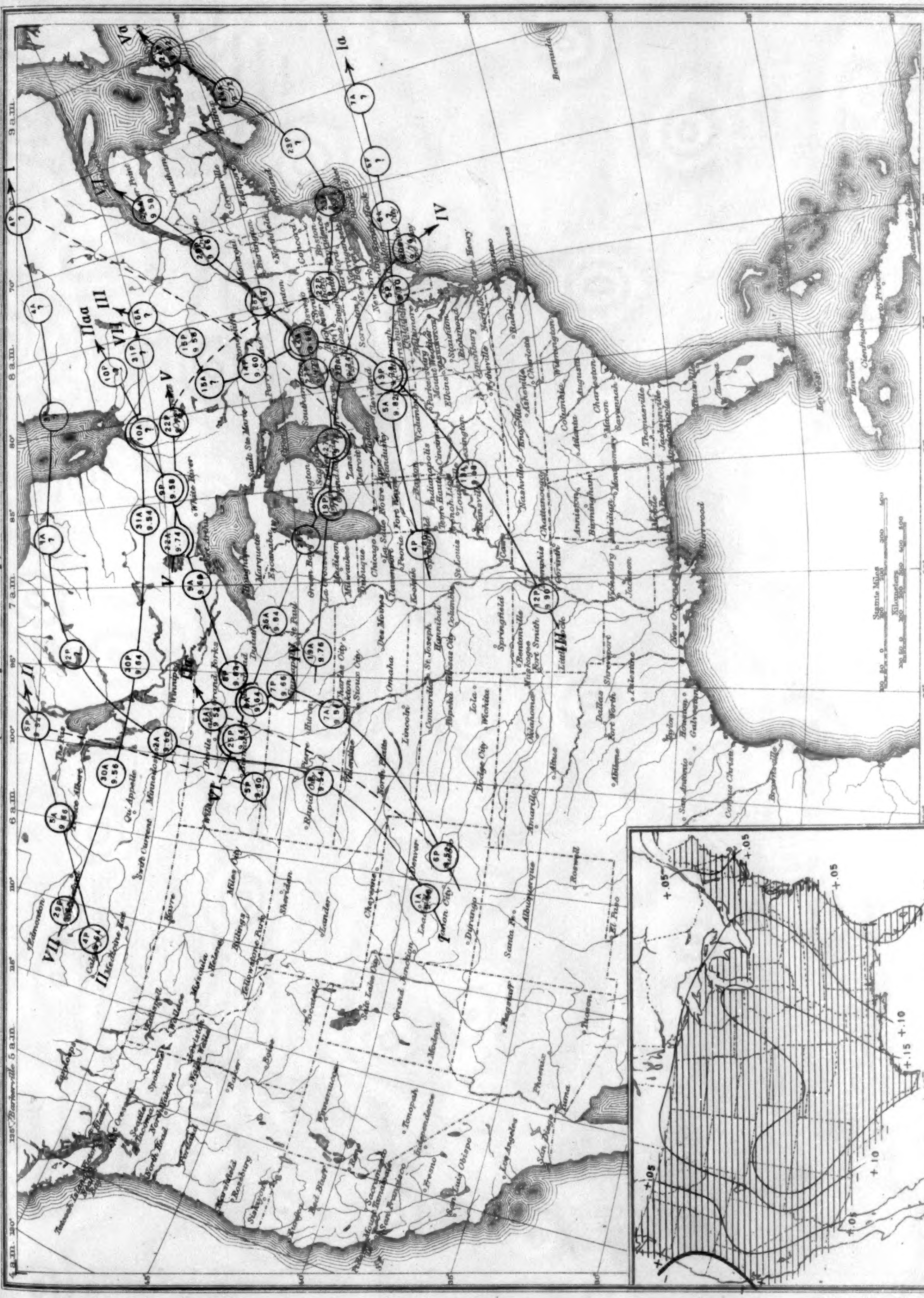


Chart III. Tracks of Centers of Cyclones, July, 1928. (Inset) Change in Mean Pressure from Preceding Month
(Plotted by Wilfred P. Day)

Chart IV. Percentage of Clear Sky between Sunrise and Sunset, July, 1928

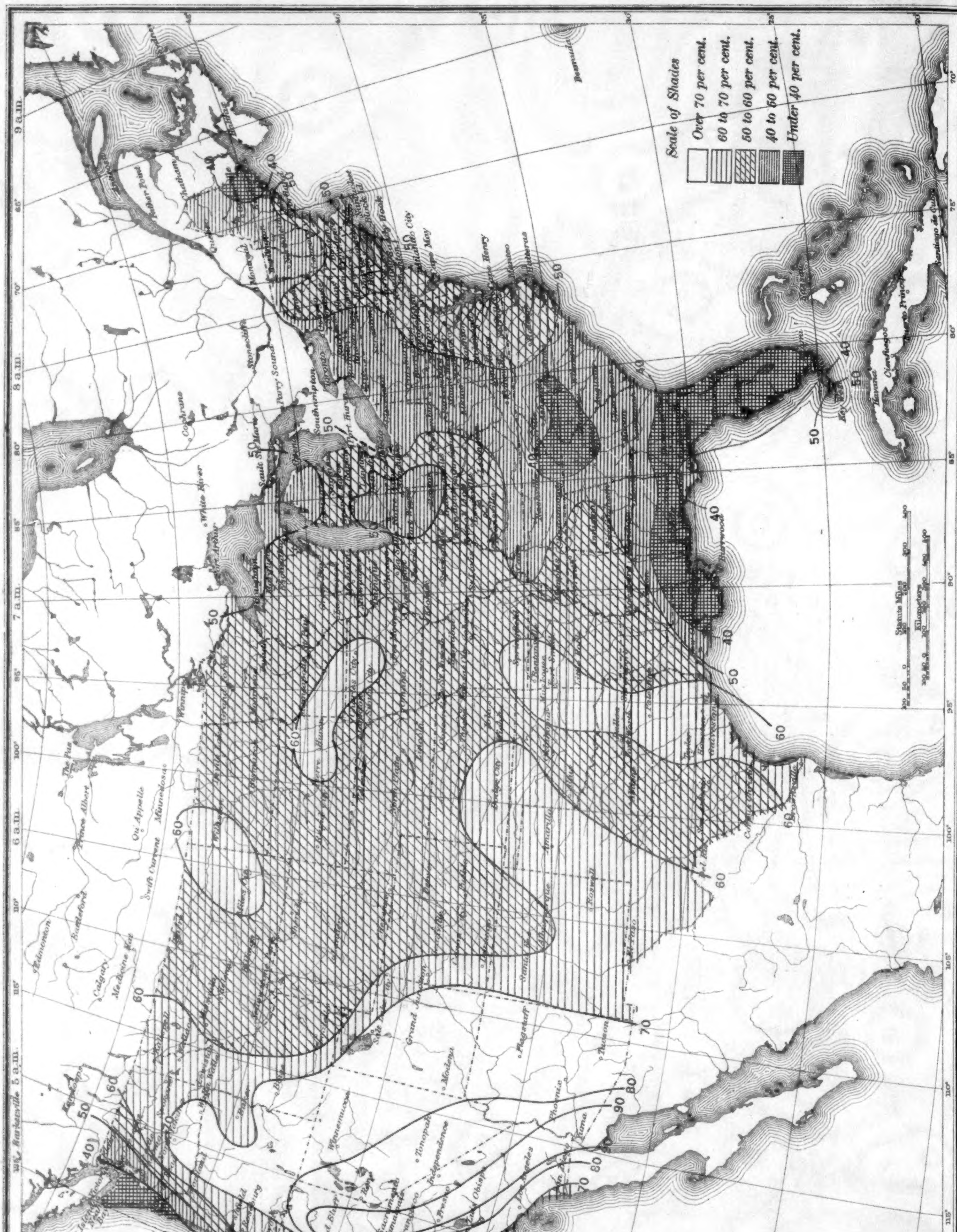
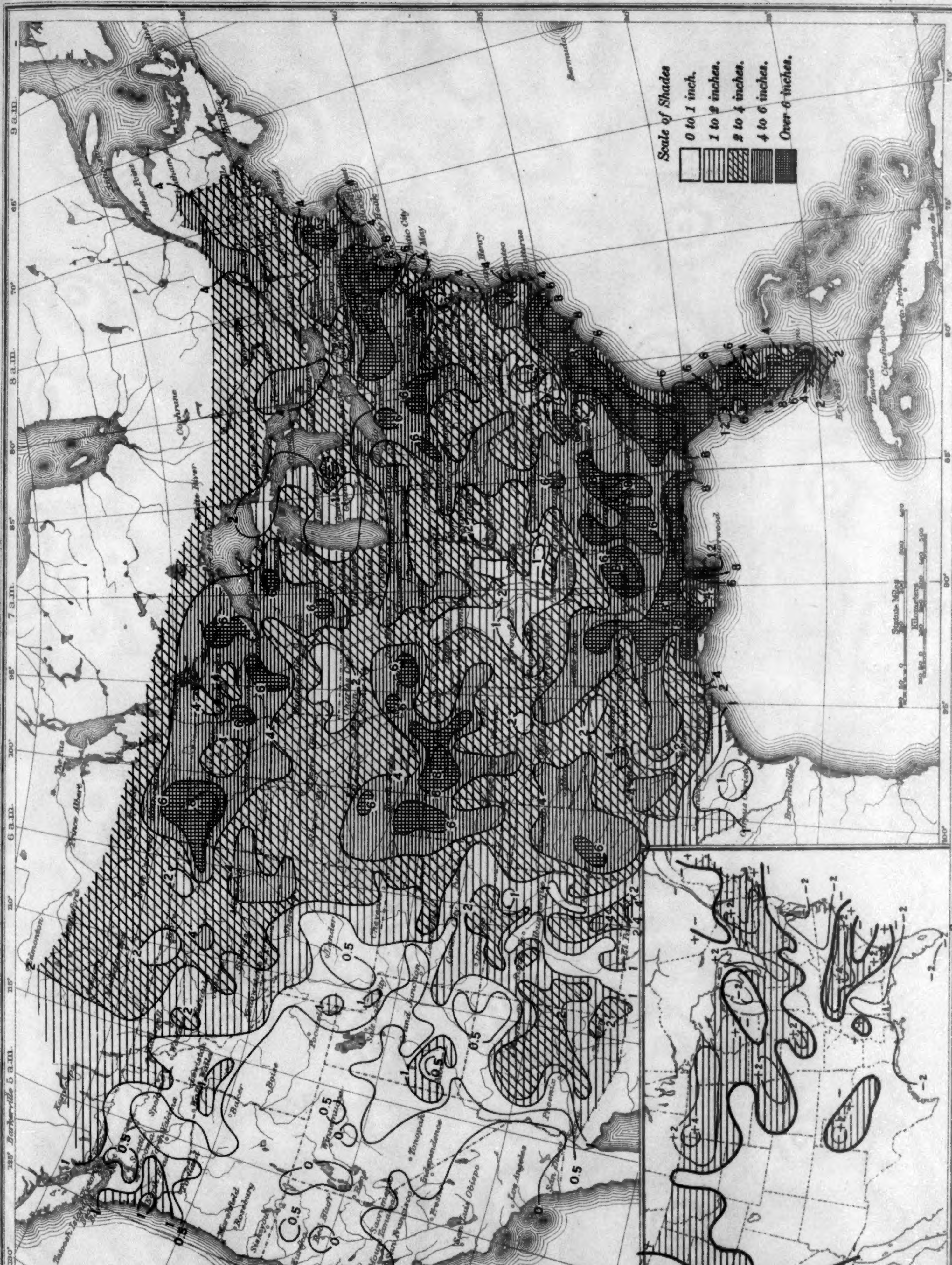


Chart V. Total Precipitation, Inches, July, 1928. (Inset) Departure of Precipitation from Normal

Chart V. Total Precipitation, Inches, July, 1928. (Inset) Departure of Precipitation from Normal



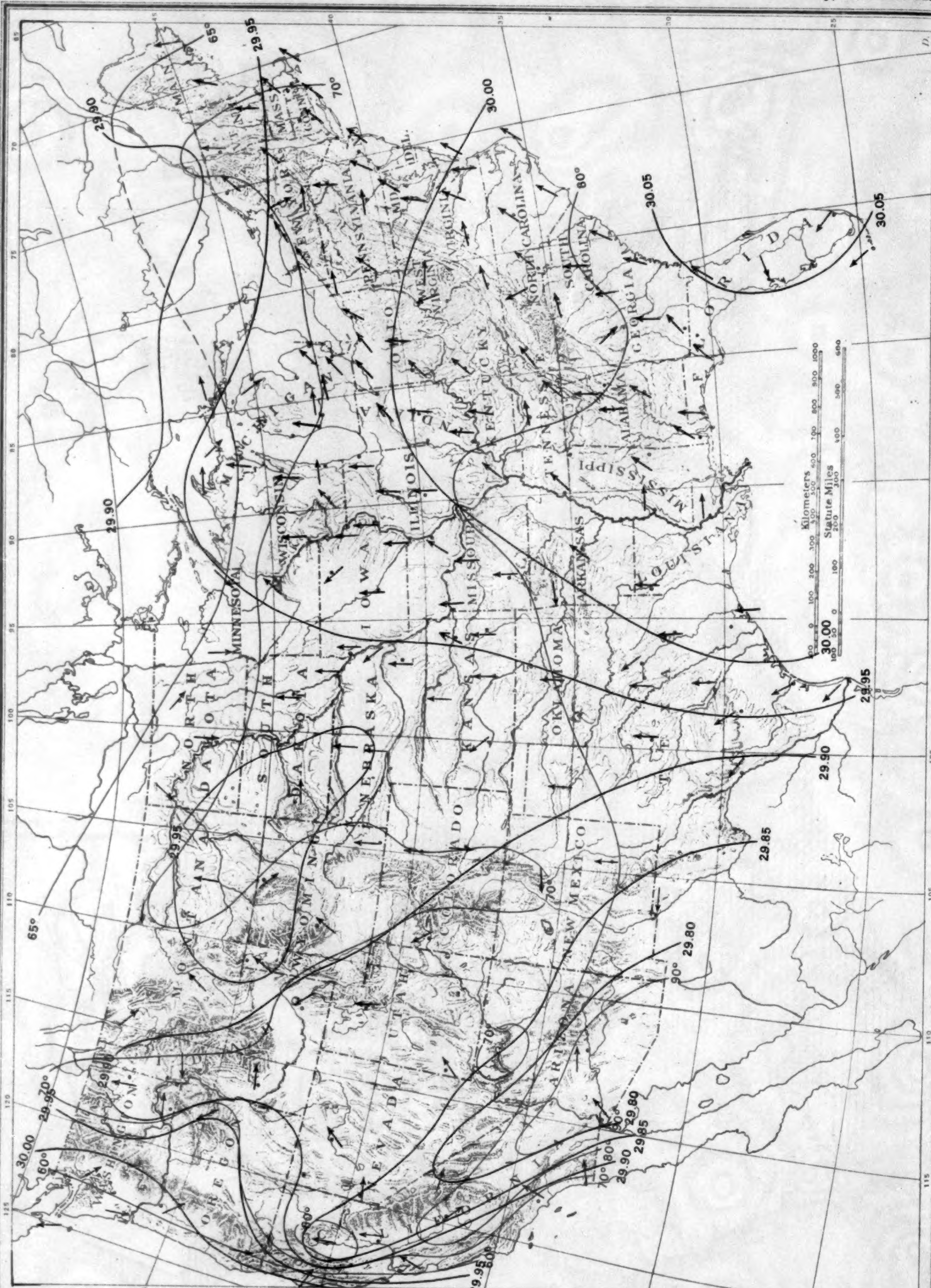


Chart VI. Isobars at Sea level and Isotherms at Surface; Prevailing Winds, July, 1928